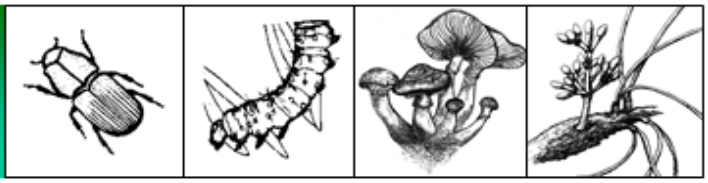
Forest Health Protection



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Root disease and other mortality agents on the Clearwater National Forest: 22-year results from Mex Mountain growth and mortality permanent plots

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SUMMARY

Permanent plot clusters were randomly located in the heart of the Lochsa Ranger District in the 14,402-acre compartment 512, the Canyon Creek watershed. The 84 clusters (252 plots) were established in 1987 and monitored annually or biannually through 2009. The plot cover types were 40% western red cedar, 35% grand fir and 17% Douglas-fir at the start, and 50% western red cedar, 33% grand fir and 11% Douglas-fir in the end. The average diameter at breast height in 1987 was 13.8 inches, and the average in 2009 was 15.8 inches. The average age in 1987 was 98, in 2009 it was 113. Over the period, 40% of the basal area present in 1987 or produced through growth, was dead by 2009. Twelve percent of this mortality was salvaged. The cumulative mortality was 56% of subalpine fir, 52% of Douglas-fir, 32% of Engelmann spruce, 31% of grand fir, and 9% of western red cedar.

By 2009, 20% of plots on grand fir habitat types had no live canopy or only a single live overstory tree remaining. On cedar habitat types this condition was found on 11% of plots. Because 244 of the 252 plots had grand fir or western red cedar habitat types, the total frequency of non-stocked plots on these types in 2009 was 13%.

Root disease alone (67%) or in combination with windthrow or bark beetles accounted for 83.5% of deaths and 83.5% of basal area mortality. Bark beetles and root diseases combined caused the deaths of 8.3% of trees, windthrow accounted for another 8.3%, and green salvage harvesting removed 7.5%. The root disease severity score was a very good predictor of overall mortality.

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OBJECTIVES

The purpose of the Mex Mountain permanent plots was to monitor for trends in root disease and mortality from all causes as influenced by host species, age, density, stand structure, site characteristics, annual weather patterns and other disturbance factors. A watershed was selected on the basis that it was typical and represented a substantial part of the Forest. The Canyon Creek watershed was recommended by the Forest Silviculturist, Bill Wulf (since retired).

The Mex Mountain project was part of a program to monitor root disease and other causes of mortality in representative forest types of northern Idaho and western Montana. The first set of plots were established on the Coeur d'Alene River District (then Fernan Ranger District) of the Idaho Panhandle National Forest in 1984 (Hagle 1985). The Mex Mountain plots were established in 1987 (Figure 1). When a west-wide permanent plot program was initiated in 1990 to promote consistency among Regional efforts to monitor dwarf mistletoes and root diseases, the Idaho Panhandle and Mex Mountain plots became part of the west-wide project. The installation methods were adopted for the west-wide plot system. In the Northern Region, 1,349 root disease plots were ultimately established in 14 project areas on seven National Forests. The projects represent a variety of important forest and site types, natural disturbances and management methods.

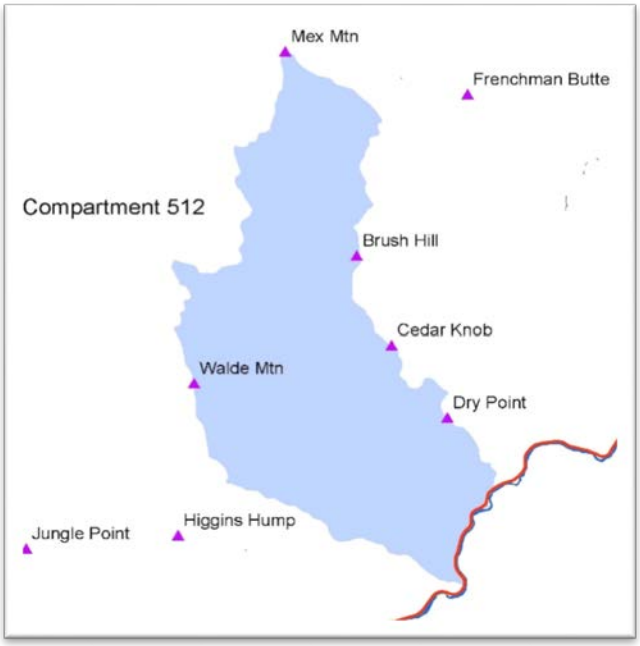


Figure 1. Location of Compartment 512 on Lochsa Ranger District.

The Mex Mountain plots monitor mostly grand fir and western red cedar habitat types, with productive mixed conifer stands, in the south-central portion of the Clearwater National Forest. The stands are generally mid to late seral and potential natural community, with little harvest activity. They are generally within an area of the forest that once supported a substantial population of western white pine. This population had already succumbed to the invasive canker disease, white pine blister rust, caused by the fungus, *Cronartium ribicola* J.C. Fisch.

All causes of mortality and other notable tree damage, tree growth and species composition changes were monitored for 22 years.

METHODS

Summary

Lochsa Ranger District silviculture technicians and seasonal crews were responsible for plot installation and monitoring. Trees 5 inches diameter at breast height (4.5 feet above ground) (dbh) and larger were tagged on fixed area 1/20-acre plots. Eighty-four, three-plot clusters (252 plots) were examined annually for six years and biannually thereafter for tree damage and mortality. Measurements for growth and in-growth were completed every 5 to 6 years.

Management activities were allowed as needed and recorded as a permanent attribute of affected plots. Several salvage sales impacted plots between 1987 and 1995. No wildfire nor controlled burns occurred on the plots during the monitoring period.

Cluster location

The clusters were randomly located over the entire watershed. Locations were chosen by placing a 0.25 inch grid over a 0.5 inch to mile scale map of the watershed, and selecting grid line intersections using a random number generator. Cluster centers became the plot center for the first plot of a cluster.

Highly disturbed areas such as recent clearcuts, developed pasture, mining claims or similarly impacted areas were excluded. Roads were avoided to reduce disturbance from firewood harvest. Plots were located no closer than 200 feet from an open road.

Once a cluster center was located, the other two plots could be offset, if needed, to avoid unacceptable or unreachable locations (such as across a non-fordable river from the cluster center). The crew did have to ford a stream to access clusters 62 and 71. Field notes reminded future crews to measure these clusters later in the season after the water level had dropped and to bring dry socks.

Installation methods

The plots were installed in 1987 according to Chapter 600 instructions of the R1 Timber Management Handbook, with a few minor modifications (such as the addition of root disease severity rating). This handbook was superseded by Forest Service Handbook 2409.13, Timber Permanent Plot Handbook, in 1992.

The basic design is three-plot clusters of 0.05 (1/20th) acre circular fixed-area plots. The plot radius was corrected for slope.

Once plot locations were confirmed on the ground, they were mapped, pricked on aerial photographs and documented with clearly marked witness trees.

Monumenting

Plot centers were staked. Azimuth and distance from plot center to growth sample trees, and a minimum of four live trees, one in each quadrant, were recorded. This was to serve for relocation of plot center if a stake was lost. Starting in 2003, latitude and longitude were measured by GPS (global positioning system), recorded for each plot, and updated or corrected during each plot inspection. Plots were sketched showing locations of mapped trees and other notable features such as downed logs, stumps, boulders, etc. (Figure 2). Likewise, cluster maps show the location of plots relative to witness trees and take-off points from roads or trails (Figure 3).

Figure 2. Each plot was sketched showing trees and significant features such as downed trees, stumps, water, and rock outcroppings. This example is plot 5601.

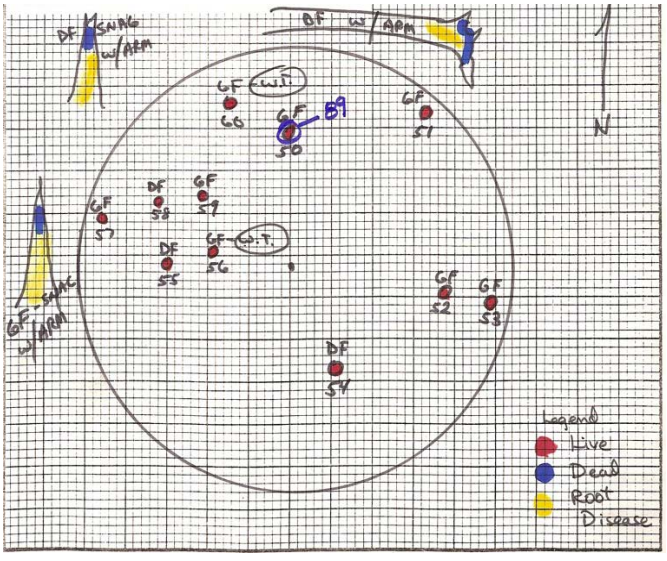
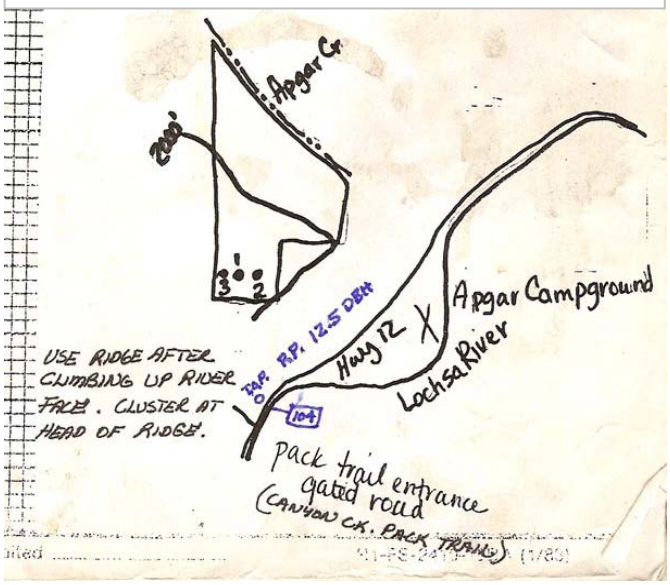


Figure 3. Sketches were drawn to document the location of clusters and help with future navigation to the location. This example shows the route to cluster 70.



Monuments deteriorated through the years and needed to be redone or improved frequently as paint and flagging faded or deteriorated. This made acquiring GPS locations all the more important for relocating plots. Takeoff points changed for many reasons. For example, witness trees died, road closures altered possible courses, and windthrow or other events altered access.

Plot and tree data

Plot and tree data were recorded according to instructions in the Region One Timber Management Data handbook FSH 2409.21h R1 Chapter 400 that was current in 1987 (USDA 1986).

Standard Plot data

Most of the plot data recorded permanent features of the site such as the percent slope, aspect, elevation, topographic position, and habitat type (potential vegetation type). The 5 or 6-year complete measurements included updating cover data to characterize the non-tree cover. These data included the type of cover, the percent coverage of the plot by the cover type, and the height of the shrubs, if the cover type was shrubs. The classes of cover ranged from bare soil, rock, duff or water to grasses, forbs, and shrubs. The plants were identified by species. The percent cover was estimated to the nearest 10%. Several cover types could be recorded for each plot.

Plot root disease severity

A plot root disease severity was assigned each plot initially and could be updated by the crew at any time during the monitoring period. This number was entered in field 33 (intended for the sample point subgroup) on card 2 of the field record form.

Root disease severity score was assigned to each plot based on visible signs of impact from root disease on the plot (Table 1). In all cases, the severity rating was applied on the basis of the amount of change from normal that was attributable to root disease. Familiarity with the local conditions is essential for application of this rating system. Distinction is drawn between the overstory (dominant and co-dominant) and understory trees that have regenerated in canopy openings; and between root disease tolerant species (referred to as resistant species), and non-root disease tolerant species (referred to as the susceptible species). Uneven-aged structure resulting from other causes is considered normal (with respect to root disease). The disease severity is based only on the changes from normal caused by root disease. This often included some bark beetle activity because beetles occasionally attack trees damaged by root disease.

It is a subjective rating system. The ordinal scale, from 0 to 9, is intended to reflect relative impacts and predict future mortality (Hagle 2010). The lack of clear distinction between adjacent classes reflects the fact that disease severity does not, in reality, jump from class to class. The crews were instructed not to be concerned if they rated a plot differently by a class. A difference of more than one class indicated that they should compare thoughts on the rating and come to an agreement.

During the training phase, field personnel were tested on the precision or repeatability of their severity rating and encouraged to compare results to increase consistency. Over the years, new crew persons were trained by experienced crew members. Of interest in severity rating is both the precision (repeatability) and the accuracy. In this case, the accuracy was reflected in how well the score predicted future mortality.

Cutting history, age, species composition, and physical features of the site must be taken into account when applying these rating systems. The crew visualized both ends of the scale, no root disease versus no surviving overstory, for each plot, and then "found" the position of the polygon or plot between the extremes. For example, where thin or dry soils limited stocking density, the `no root disease' end of the scale had considerably less canopy than sites with higher site potential.

Table 1: Root Disease Severity Rating	
Code	Criteria
0	No evidence of root disease visible within 50 feet of plot.
1	Root disease present within 50 feet of plot but no evidence of disease on plot.
2	Minor evidence of root disease on plot, such as a suppressed tree killed by root disease, or minor part of overstory showing symptoms of infection. Little or no detectable reduction in canopy closure or volume.
3	Canopy reduction evident, up to 20 percent. Usually as result of death of one co-dominant tree on otherwise fully stocked site. In absence of mortality, numerous trees showing symptoms of root disease infection.
4	Canopy reduction 20 - 30 percent as result of root disease-caused mortality. Snags, and downed trees removed from canopy by disease as well as live trees with advanced symptoms of disease contribute to impact.
5	Canopy reduction 30-50 percent as result of root disease. At least half of ground area of plot considered infested with evidence of root disease-killed trees. Plots representing mature stands with half of their volume in root disease-tolerant species usually don't rate above severity 5 because of the ameliorating effect of the disease tolerant trees.
6	50-75 percent reduction in canopy with most of ground area considered infested as evidenced by symptomatic trees.
7	At least 75 percent canopy reduction. There are very few of the original overstory trees remaining although the infested ground area often is densely stocked with regeneration of the susceptible species.
8	The entire plot falls within a definite root disease patch with only one (if a plot) or very few (if a stand) susceptible overstory trees present. Stands with a disease-tolerant overstory rarely reach 8 or 9.
9	The entire plot falls within a definite root disease patch with no live overstory trees present.

Plot Root Disease Severity Rating Procedure

Some crew members preferred to visualize canopy reduction while others were more comfortable estimating the ground area of the plot that is impacted. The ground area impacted is especially applicable to young stands such as sapling size where canopy closure would not have occurred even in the absence of root disease and in partially harvested plots where it could be difficult to visualize the difference between the canopy-opening effects of the harvest and the effects of root disease. The ground area impacted is estimated by projecting the drip line of the crowns of overstory trees to the ground to estimate the percentage of the area occupied by trees with symptoms of root disease. If the field personnel tried to make the process too precise, the advantages of the rating system as a rapid assessment technique would have been lost. The objective was to quickly estimate the relative impact of root disease. The canopy reduction classes are described in Table 1.

Tree data

Chapter 400 instructions were followed to record for each tree: species, diameter at breast height, tree condition class, crown class and observed damages. Up to three damages could be recorded for each tree at each inspection. A severity class was recorded for each damage. There was no implied priority or importance in the order that the three damages were recorded although the crews were instructed to record the damage types that had the most impact on the tree before recording less serious damages.

Growth sample trees (GST)

The growth sample tree is intended to represent a class of trees with respect to age and growth measurements. In practice, they are the first live tree of each species and diameter class (Table 2) encountered on plot when proceeding in a clockwise direction from a 0° azimuth.

The GST was cored to determine total age and radial increment growth in the last 5-years. Total height was measured for each GST. These measurements were updated at the 5 or 6 year complete measurements at which time new GST were selected as necessary. This included replacing GST that had died since the last complete cycle.

Table 2. Growth Sample Tree diameter classes
5.0—8.9 inches dbh
9.0-14.9 inches dbh
First tree >15 inches dbh
Largest tree >15 inches dbh

Disease and insect diagnosis

Because of the permanent nature of the plots, limits were placed on the amount of digging or chopping that could be done to identify diseases or insects impacting trees. Live trees could not be damaged by the examination to ensure that the process would not alter the course or timing of the disease or insect attack. Dead trees could be examined somewhat more aggressively but not to the extent that the plot was overly disturbed. Minor digging and chopping away some bark to confirm the presence of mycelium or bark beetle galleries was acceptable for adequate diagnosis on dead trees.

RESULTS

Overview of the project

Eighty-four 3-plot clusters were installed in 1987. The 252 plots installed for the Lochsa project cover an equivalent of 12.6 acres. A total of 2,664 trees were monitored during the period from 1987 through 2009. Of these, 2,168 were alive and 395 were dead at the time of plot installation. Dead trees were monitored primarily for deterioration rates and to track potential sources of inoculum for root diseases. Another 612 trees died during the monitoring period. In-growth added 101 trees after plot establishment.

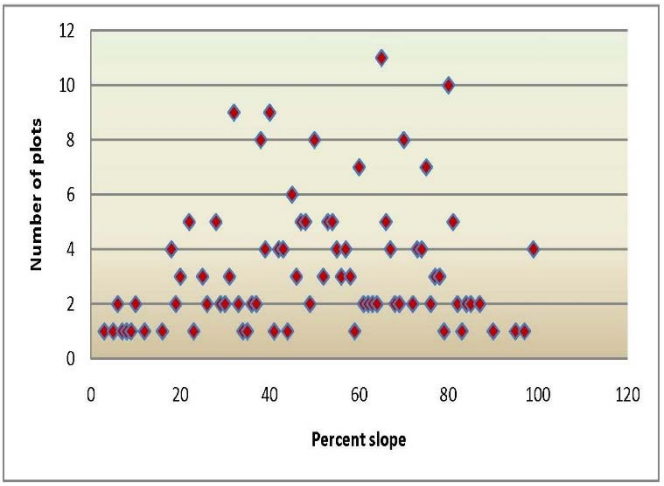
Conservation of plots

Of the 84 clusters, all but one cluster and one plot of another cluster survived the entire period through 2009. Cluster 15 was obliterated by a large windthrow event in 1987 and subsequent salvage logging in 1988. The plots could not be relocated following the harvest. In addition, road construction obliterated plot 3702 in 1992. At final tally in 2009, 248 plots were still intact and, although some plots were missed on occasion, especially during mortality and damage checks, most have been examined each period throughout the entire 22 years.

Regularity of observations

Of the 39,960 possible tree observations, 1,357 observations (3%) were missed. Of these, 781 (>2%) would have been live trees at the time the observation was missed. Few of the omissions occurred at major intervals, when complete tree measurement was done. Cluster 15, plots 1-3 and cluster 37, plot 2 had to be abandoned after wind damage and/or harvest activity caused the loss of the plot center stakes and all of the mapped trees that would have allowed relocation of the plot center.

Figure 4. Distribution of plots by percent slope.



Plot characteristics

Slope, aspect, topographic position, elevation, habitat type, and plot root disease severity score all varied greatly among the plots. The plot-level characteristics remained static through the project, with the exception of plot root disease severity.

Slope

Typical of the Clearwater National Forest, most plots (85%) fell between 20% and 80% slope and four had 95-99% slope (Figure 4).

Aspect

The plots are broadly distributed on the north side of the Lochsa River, accounting for a few more of the plots having southerly aspects (44%) versus northerly aspects (31%). Likewise, a few more plots have easterly (41%) than westerly aspects (31%). Northwest is the least represented aspect with roughly half as many plots as the others (Figure 5).

Topographic position

Over two thirds of plots (175) fell on an even bench or even slope (Figure 6). Only one plot was classified as a sheer cliff. It had one tree at plot establishment, an 11.6 inch dbh Douglas-fir that died from root disease and Douglas-fir beetle attack between 2001 and 2003.

Elevation

The elevation range of plots is 3400 feet, from 1600 feet on plots near Apgar Campground on the Lochsa River, to those at 4800 feet near Mex Mountain (Figure 7). This is a typical and common range for mid to lower elevation forested sites on the Clearwater National Forest and other forest ownerships in north-central Idaho.

Habitat type

A key characteristic from the standpoint of productivity and damage agents, such as root disease and white pine blister rust, is habitat type. Western red cedar habitat types (75% of plots) were well represented in our sample (Figure 8). Grand fir habitat types were found on 23% of plots. Subalpine fir and Douglas-fir habitat types were each found on less than 2% of the plots.

Potential vegetation types

The plots were classified according to the northern Idaho and western Montana Potential Vegetation Type (PVT) classification scheme (Jones 2004). The PVT classification scheme was developed by Jeff Jones for the National Fire Plan Cohesive Strategy Team. It aggregates habitat types into ecologically similar types based on temperature and moisture. Four types dominated on the Mex Mountain plots. These were thpl2 at 51.2%, thpl1 at 23.8%, abgr3 with 13.5% (all classified as warm moist), and abgr1 with 8.3% (classified warm dry) (Figure 9). The other three corresponded to habitat types with less than 2% representation.

Metrics by species

The initial tree metrics are shown in Table 3. The constancy of species is shown as the number of plots on which the species is present. On average, the overall stocking of live trees at least five inches dbh in 1987 was 172 trees per acre and 239 square feet of basal area per acre. Table 4 shows the number of the original

Figure 5. Aspect (percent of plots).

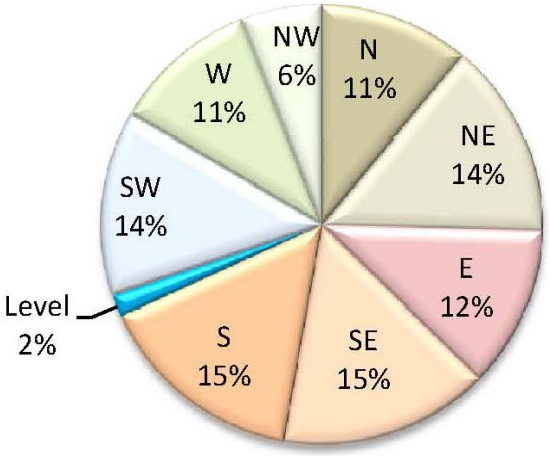


Figure 6. Topographic position (percent of plots).

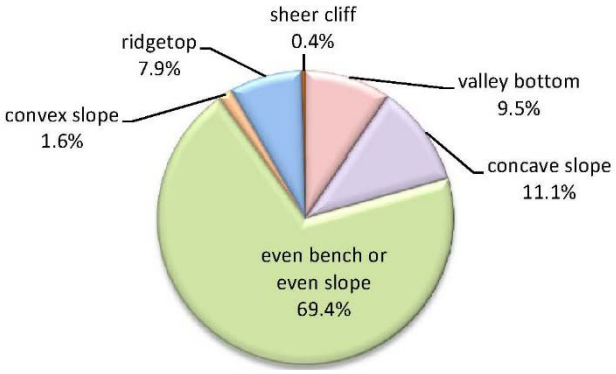
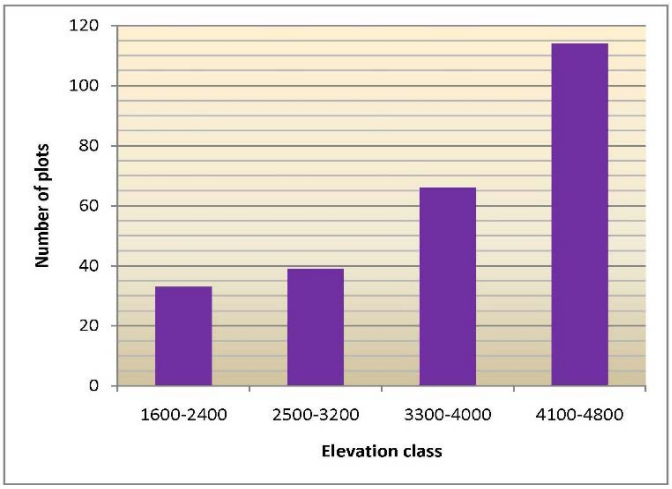


Figure 7. Number of plots by elevation.



tagged trees (excluding ingrowth) that were still alive at each of the subsequent mortality checks and plot remeasurements (shaded gray).

The dead trees and stumps of harvested trees recorded at the time of plot installation tell much of the history of the stands (Table 3). All of the white pine on the plots in 1987 were dead and about a third had been salvaged, indicating a history of white pine blister rust. Nearly a third of the Douglas-fir and about 20% of the grand fir were dead and root disease severity scores suggested a long history of root disease impacts. Few early seral species (western larch, ponderosa pine, western white pine and lodgepole pine) were present. Western red cedar was already the most populous species (number of stems and basal area) at the beginning of the monitoring period and increased in number of stems from 41% in 1987 to 50% in 2009. During this period Douglas-fir decreased from 17% to 11% of the composition.

Figure 8. Distribution of habitat types by percent of plots. See table 10 for habitat type codes.

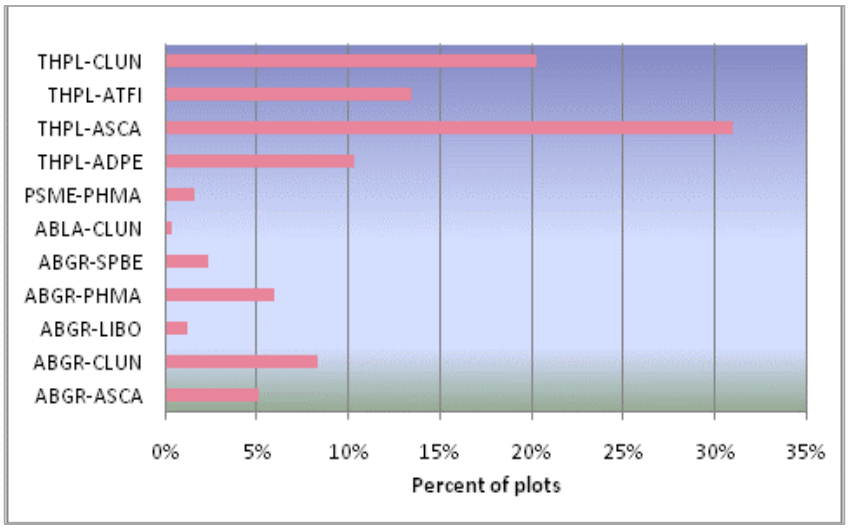
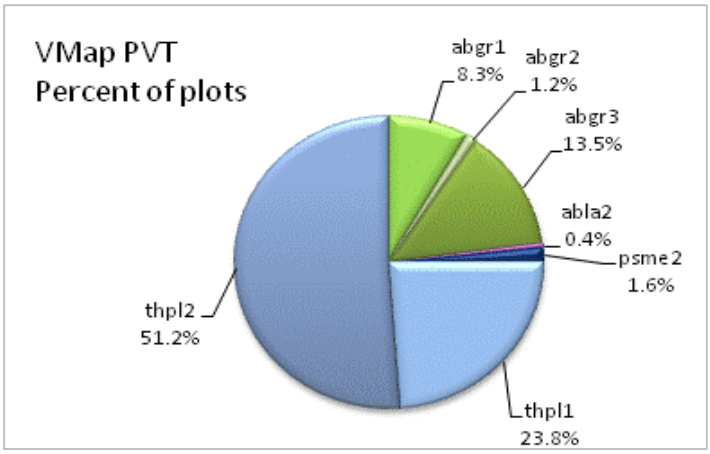


Figure 9. Potential Vegetation types. Table 10 has PVT codes.



Timber Salvage

Several plots were impacted directly by harvest of tagged trees. Twenty six plots had trees harvested in the period 1978 to 1997 (Table 5). Six had been salvage harvested up to a decade before plot installation and one was installed in a stand that had been shelterwood preparatory cut in 1973. After plot installation, twenty additional plots were salvage harvested, removing an average of 57% of the trees (Table 6). Of 221 trees on the 26 plots with some harvest, 104 trees were harvested. In many cases, trees were dead at the time of salvage, generally from root disease.

More than half (53) of the 104 harvested trees had been diagnosed with root disease or blister rust, had been attacked by bark beetles, or had been windthrown. Excluding the trees that were dead in 1987, 117 unharvested trees were tracked on salvaged plots. On plots where the major species removed was western white pine (presumably white pine blister rust salvage), the residual trees had an 86% survival rate in 2009. In contrast, where Douglas-fir and grand fir were the main species removed, and root disease and bark beetles were the most likely reason for the salvage, only 13% of the residuals were alive in 2009.

As for harvest effects on residual trees, little could be concluded from the relatively high rate of mortality of residual trees on salvaged plots because mortality on the plots was presumably the motivation for salvage. Therefore, the salvage activities may have been directed toward stands with already high rates of root disease. Stand or site disturbance, logging injury of residual trees and stimulation of root pathogens by stump-creation also may have increased mortality rates in the residual population.

Distribution of mortality

Figures 10 and 11 show the number and percent of trees killed on plots, excluding green salvage. Nearly a third of the plots had no mortality recorded over the 22 year period (figure 10). This statistic is deceiving, however. Of

Table 3. Species metrics on plots in 1987.

1987	Total trees	Live trees	% live composition	Live BA	Live Average DBH	Average age GST*	# plots present
Subalpine fir	54	43	2.0	19	8.6	89	22
Western red cedar	922	879	40.5	1364	14.0	98	166
Douglas-fir	533	375	17.3	509	14.4	94	152
Grand fir	895	765	35.3	954	13.3	96	220
Western larch	4	2	0.1	3	17.1	83	3
Lodgepole pine	9	6	0.3	5	11.7	80	5
Ponderosa pine	9	7	0.3	20	22.3	132	8
Engelmann spruce	101	91	4.2	133	15.2	117	47
Western white pine	36	0	0.0	0	0	0	18
All species	**2563**	**2168**	**100.0**	**3008**	**13.8**	**98**	**252**

Table 4. Trees alive in 1987, in-growth not included. The number alive at each interval.

Year	1987	1988	1989	1990	1991	1992	1993	1995	1997	1999	2001	2003	2005	2007	2009
Years	0	1	2	3	4	5	6	8	10	12	14	16	18	20	22
Subalpine fir	43	43	43	43	43	42	34	34	31	30	29	24	24	22	19
Western red cedar	879	879	879	876	874	872	860	848	833	829	827	812	811	811	776
Douglas-fir	375	368	352	349	337	327	321	306	278	262	249	233	226	215	180
Grand fir	765	759	747	743	728	707	702	679	642	632	622	591	588	574	523
Western larch	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Lodgepole pine	6	6	6	6	6	6	6	6	5	5	5	5	5	5	5
Ponderosa pine	7	7	6	5	5	5	5	5	5	5	4	4	4	4	4
Engelmann spruce	91	90	90	90	90	87	80	78	70	69	68	66	66	66	59
All trees	**2168**	**2154**	**2125**	**2114**	**2085**	**2048**	**2010**	**1958**	**1866**	**1834**	**1806**	**1737**	**1726**	**1699**	**1568**

these 64 plots with no mortality from 1987 to 2009, 13 already had so much root disease impact, there were no susceptible trees left to die (severity classes 8 and 9). A few plots had very high rates of mortality, including 18 plots (7.2%) on which all remaining trees died (figure 11). But most mortality was well-distributed among the plots with one or two trees the most common number of deaths. The percent mortality was well distributed. This indicated that the damaging agents were well distributed in the Canyon Creek watershed.

Table 5. Harvests	
Harvest period: 1973-1997	
Year	plots
Pre-1987	7
1987	3
1988	3
1992	4
1993	3
1996	6
1997	1
Total	*26*

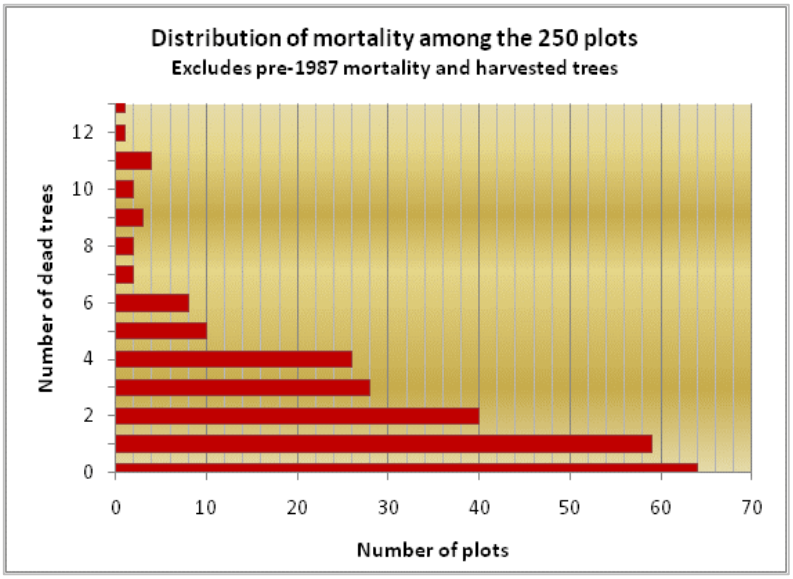
Table 6. Tree harvest on plots		
Plots w/ harvest = 26; 1 shelterwood, 25 salvage		
Previous damage	Plots	% of plots
Windthrow	5	0.2
Root Disease	19	0.76
Bark Beetles	2	0.08
White pine blister rust	7	0.28
104 trees were cut		
117 residual trees on cut plots		
13%	survival after RD salvage	
86%	survival after WPBR salvage	
33%	Average cut on plots before 1987	
57%	Average cut on plots after 1987	

Basal area 1987-2009

Most plots ranged between 100 and 400 sq. ft./ac. of live basal area in 1987. By 2009, about half of the plots lost and half gained basal area, for a net loss of live basal area less than 1% overall (Figure 12). This small overall change in basal area is deceptive; nearly all individual plots experienced substantial changes in both basal area and species composition.

Dead basal area increased about 93% overall from 627 ft^2/ac in 1987 to 1,483 ft^2/ac in 2009. Most of this (90%) occurred in the three most common species on the plots, grand fir, Douglas-fir and western red cedar (Figure 13). The species most affected by mortality as a proportion of their initial total basal area, however, were subalpine fir (58%), Engelmann spruce (41%), and Douglas-fir (37%).

Figure 10. Distribution of mortality among plots as number of trees killed by the number of plots.



The number of plots with less than 50 sq. ft./ac. of basal area increased almost threefold from 13 in 1987 to 37 in 2009. Seven of these stands had been salvage harvested and the rest had root disease severity rated 8 or 9 in 2009. At the end of the period, 60% of the unharvested plots had less than 250 sq. ft./ac. of basal area (Figure 13). This is very light stocking for what had been a mature forest 22 years earlier, particularly on western red cedar and grand fir habitat types.

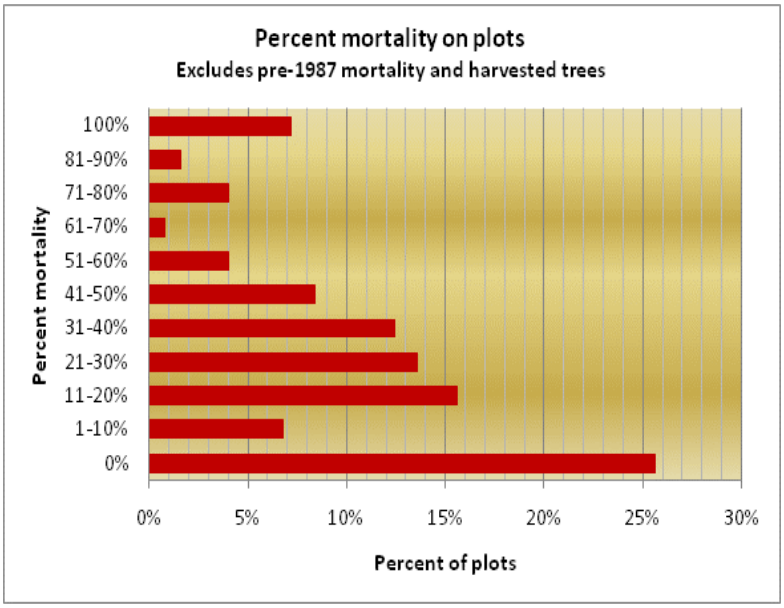
Periodic changes in BA

Rates of non-harvest mortality varied considerably among the measurement periods. Peak periods for mortality were 1989, 1994-1995, 1996-1997, 2002-2003 and 2008-2009 (Figure 14). The largest loss of basal area occurred in the 2008-2009 period when 158 sq. ft./ac. of basal area died on plots. This brought the cumulative mortality, as a percent of the total basal area at the start of each period, to 21%.

Changes by tree species

The initial species composition was typical of mature mid to late seral stands on the Lochsa District. A few early seral species were present: ponderosa, lodgepole and western white pines, and western larch (Table 7). Most occurred as a single tree of the species on a plot. Their combined average composition was just over 1.2 trees per acre in 1987 and decreased to 1 tree per acre by 2009. The ponderosa pine may have been residual overstory trees with average diameter and age indicative of an older cohort than the majority species (Table 8). Western white pine was all dead at the time of plot installation. The 36 dead white pines averaged 22.8 inches dbh. They were distributed across 18 plots and would have been part of the cohort represented by the ponderosa pine. Engelmann spruce also tended to be somewhat larger and older than the majority of trees. The 91 Engelmann spruce were distributed as one to a few trees per plot on 47 plots.

Figure 11. Distribution of mortality among plots as percent of trees killed by the percent of plots.



Western red cedar was the most abundant species in 1987 as well as 2009. It is interesting to note that in 1987, live western red cedar occurred on 65% of plots but this number was reduced by 9 plots to 61% by 2009. There were 57 in-growth during the survey time. Seventy five percent of plots have western red cedar habitat types. Live basal area of western red cedar increased by 17% from 1987 to 2009.

Grand fir was the second most abundant species. It is the ecological climax species on 22% of the plots (55). Live grand fir occurred on 87% of plots in 1987 and 74% in 2009 with 27 in-growth. They were 0.5 inches less than the average dbh in 1987 at 13.3 inches, and increased to 15.6 inches average dbh by 2009 (still 0.2 less than average). Grand fir live basal area decreased to 94% of the 1987 level by 2009.

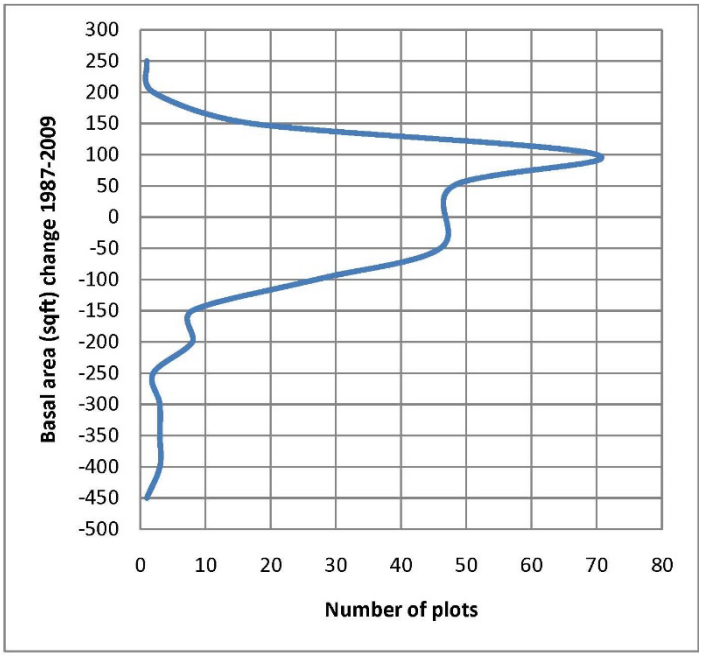
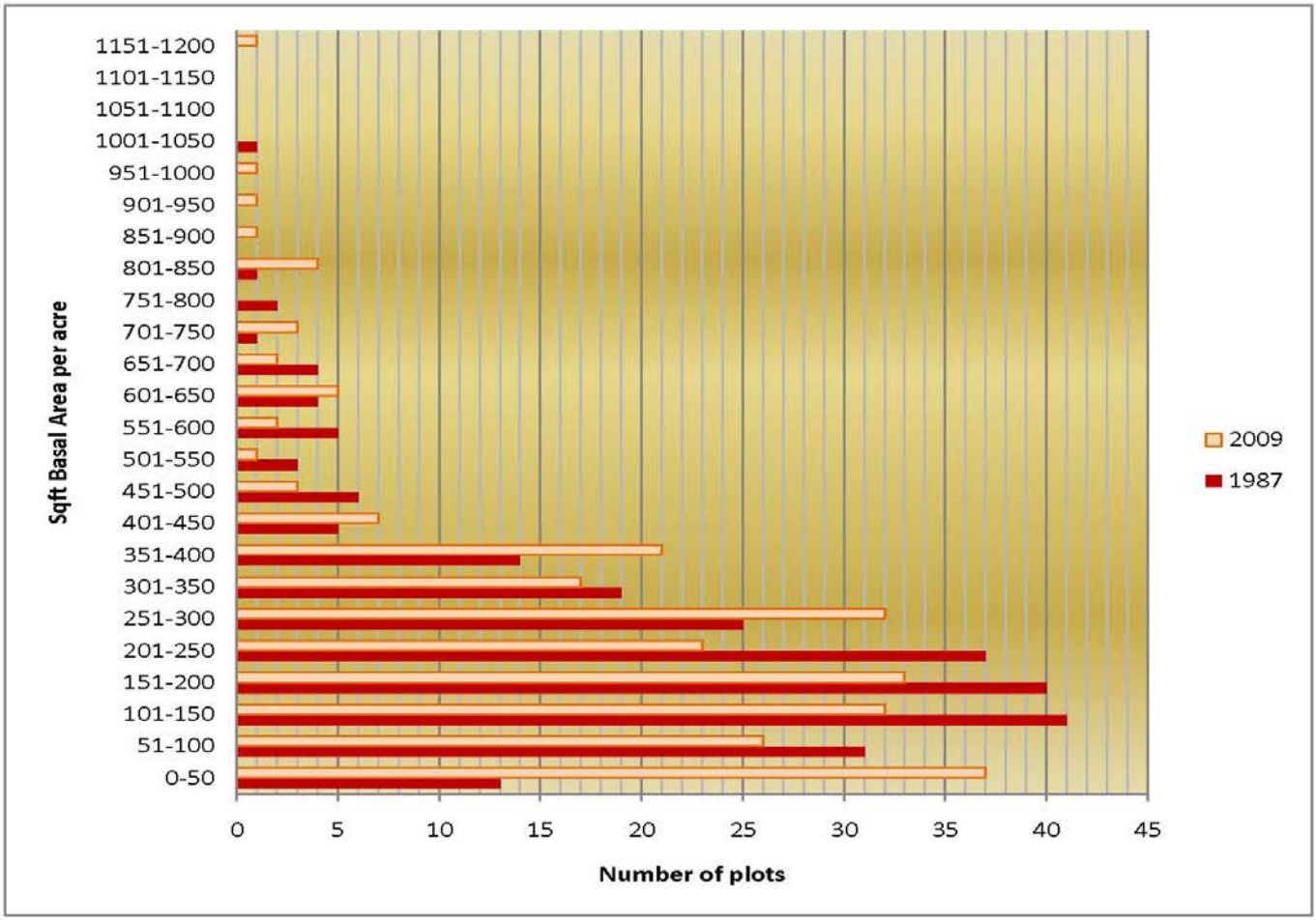


Figure 12. Change in basal area 1987 to 2009.

Douglas-fir was still an abundant species in 1987 but nearly a third of the Douglas-fir on the plots were already dead. Sixty percent of plots had at least one live Douglas-fir in 1987. Only three Douglas-fir were added as in-growth, two of which died from root disease, during the 22 years. By 2009, live Douglas-fir were present on just 36% of plots, but they had maintained a similar position in the forest, about average in age and dbh. Live basal area declined to 70% of the 1987 level.

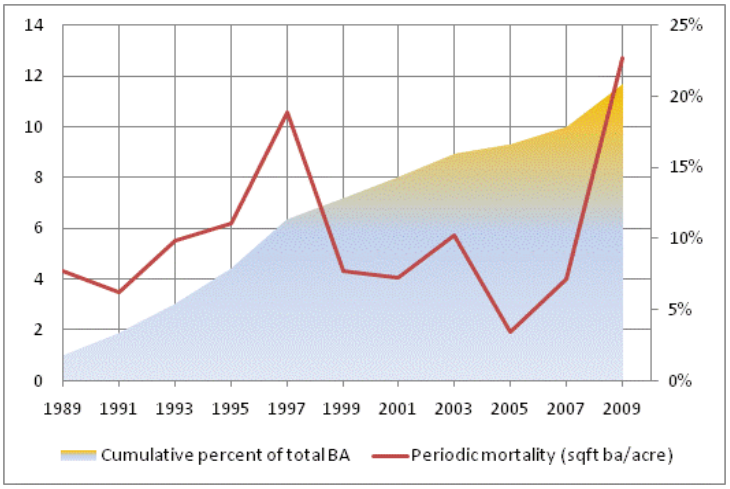
Subalpine fir was also fairly well distributed considering there were only 43 live trees in 1987. Live trees occurred on 21 plots in 1987 and 16 plots in 2009 when there were 27 live trees (including 11 in-growth, three dying from root disease). Live basal area of subalpine fir decreased to 78% of the1987 level.

Figure 13. Distribution of plots by basal area per acre in 1987 and 2009.



Although a small component of the plots, Engelmann spruce had significant reductions in number of stems and live basal area from 1987 to 2009. Diameter of live trees did increase slightly. Engelmann spruce occurred on only 47 plots, but almost all of these had some evidence of root disease by 2009. In-growth was limited to two individuals.

Figure 14. Periodic mortality in square feet/acre of basal area (left axis) compared to cumulative mortality as a percent of the total basal area in each period (right axis). Harvested trees were excluded.



By 2009 there were 12 plots on western red cedar habitat types that had no live western red cedar that were at least 5 inches dbh. Although western red cedar increased from 40% in 1987 to 50% of the trees in the project in 2009, it did so because of the loss of other tree species, rather than by increasing extent (number plots on which it occurs). The average age of western red cedar growth sample trees increased slightly from 98 in 1987 to 111 in 2009. The depression of average age, considering time between measurements, was mostly due to the addition of 57 young trees as plot in-growth. The average dbh of western red cedar increased nearly two inches from 14.0 to 15.8.

Table 7. Species metrics in 1987 and 2009. 1987 totals include trees dead (or harvested) at the time of plot installation. The 2009 values also include in-growth.

	1987 Total trees	1987 Total BA	1987 Live trees	1987 Live BA	2009 Live Trees	2009 Live BA	BA mortality	BA harvest or salvage
Subalpine fir	54	27	43	19	27	14	24	5
Western red cedar	922	1477	879	1364	827	1592	270	67
Douglas-fir	533	702	375	509	181	355	451	16
Grand fir	895	1146	765	954	548	902	538	25
Western larch	4	7	2	3	2	5	4	4
Lodgepole pine	9	6	6	5	5	5	2	0
Ponderosa pine	9	24	7	20	4	15	10	0
Engelmann spruce	101	149	91	133	61	96	77	19
Western white pine	36	108	0	0	1	1	108	38
Total	***2563***	***3646***	***2168***	***3008***	***1656***	***2984***	***1483***	***174***

Table 8. Species metrics in 1987 and 2009 for live trees. The 2009 values also include in-growth.

	1987 Average DBH	1987 Average Age GST[1/]	1987 Average RRSV[2/]	2009 Average DBH	2009 Average age GST[1/]	2009 Average RRSV[2/]	1987-2009 BA (sq. ft.) Growth	1987-2009 Non-harvested mortality BA
Subalpine fir	8.6	88	4.3	9.4	95	5.2	11	15.6
Western red	14.0	96	3.8	15.8	110	5.4	385	106.1
Douglas-fir	14.4	90	4.4	17.4	116	6.4	104	258.8
Grand fir	13.3	91	4.2	15.6	110	6.1	294	338.2
Western larch	17.1	83	3.8	20.5	105	7.5	1	0
Lodgepole pine	11.7	77	2.7	13.4	106	6.0	1	0.4
Ponderosa pine	22.3	132	5.1	26.1	176	5.7	1	6
Engelmann spruce	15.2	118	4.2	16.1	129	6.0	24	56
Western white				7.5	60	5.9	0.3	0
All Trees	***13.8***	***93***	***4.1***	***15.8***	***112***	***5.9***	***822***	***781***

[1/] Average age of live growth sample trees (GST). [2/]Average root disease severity score for plots weighted by the number of tree of the indicated species.

BA trends for species

Excluding harvested trees, the net change in basal area (growth minus mortality) was negative for all of the major species except western red cedar (Figure 15). Douglas-fir had the largest change in net basal area, ending the 22-yr period with just over 30% less basal area than it had at the beginning. Western red cedar had the next largest change with a 21% gain in basal area. Both Engelmann spruce and subalpine fir had large losses in basal area, both ending with 25% less than in 1987. Although 31% of grand fir trees died, growth of surviving trees was sufficient to reduce the net loss of basal area to only about 5% over the period.

Because of the large gain in western red cedar basal area, the overall net change in basal area on the plots was a loss of less than 1% over the 22 year period with the exclusion of harvested trees.

The trend lines for basal area change (Figure 16) illustrate the large differences between Douglas-fir, grand fir and western red cedar, the main species on the plots. The net rate of basal area loss for Douglas-fir is more than six times greater than that for grand fir. The growth rate of western red cedar produced a net basal area increase just under 1% per year.

Figure 15. Net change in basal area from 1987 to 2009, excluding harvest.

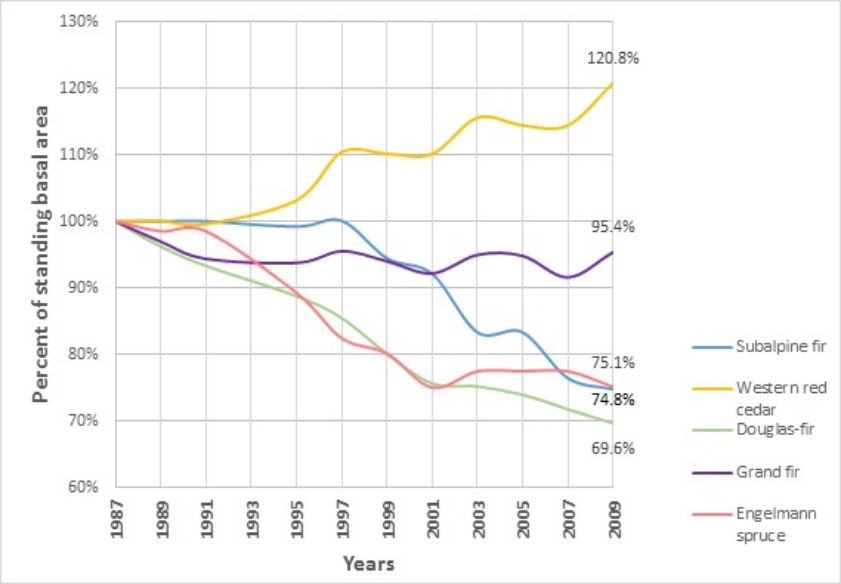
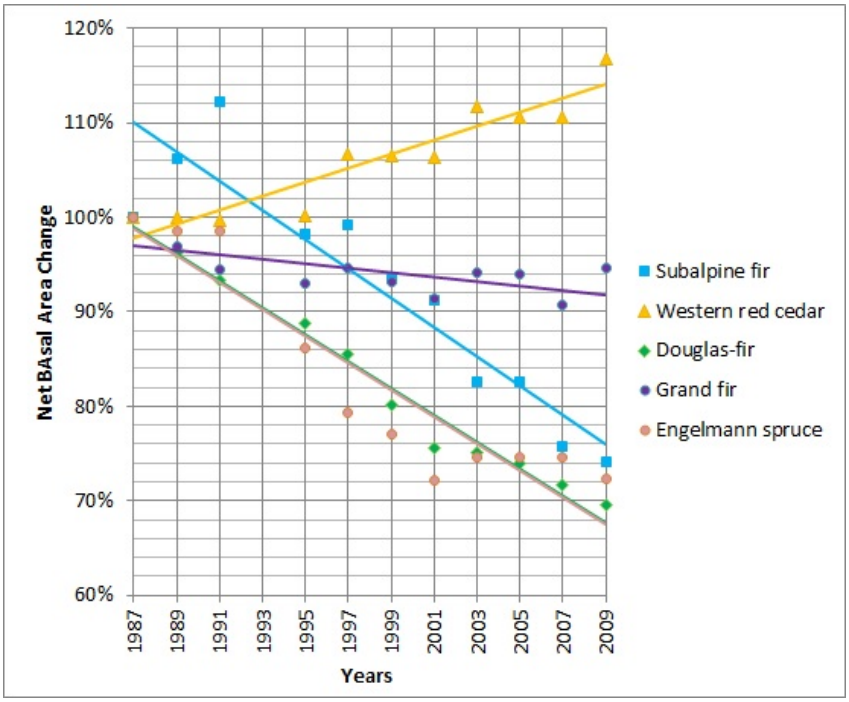


Figure 16. Trends for live basal area change for the major species over the 22 year monitoring period. Excludes harvested trees.



Survival of trees from the original population

Excluding the in-growth trees and live salvage, the survival trends show western red cedar with the best survival and subalpine fir with the lowest survival rate for number of stems (Figure 17). This chart also illustrates that both grand fir and subalpine fir have lower survival rates than are reflected in the basal area changes for these species. Growth in these species compensated for much of the basal area loss from mortality. Growth of Douglas-fir also somewhat compensated for mortality losses. Only 48% of the original Douglas-fir survived (Figure 17) but growth of these trees resulted in retention of 70% of the starting live basal area of this species (Figure 15). Growth was not much of a factor for Engelmann spruce, however. With a 35% mortality rate in the unharvested population, this species had 29% less basal area after 22 years.

Periodicity of mortality by species

Pulses of mortality driven mostly by root diseases and windthrow varied among the species (Figure 18). The first six years, when plots were examined annually, the periodicity could be seen to vary more significantly among the species. The loss of resolution after year 6 can be seen as apparent pulses that appear to peak in the same years

for all species. It is likely the pattern of actual mortality is more similar to the first 6 years. There were however significant pulses of mortality in some periods, especially for subalpine fir.

Figure 19 better illustrates the overall trends by showing the average annual loss of trees in each of the major measurement intervals. The periods 1993-1997 and 2004-2009 had higher overall rates of loss, driven largely by high rates of Douglas-fir and grand fir mortality because these species are far more populous in the sample than subalpine fir and Engelmann spruce. A disturbing trend is the increasing rate of mortality of western red cedar. Although still low, it has increased from 0.14% to 0.74% per year. In 2009, this species constituted 50% of the plot composition so increases in mortality of this species will have increasing impact on stand stocking and canopy loss.

Rates of mortality by species

Considering only the trees in the original population of live trees tagged in 1987, and excluding any trees that were live-harvested, subalpine fir had the highest mortality rate at 56% of 43 trees in 22 years (Figure 20). This species had an average annual mortality rate of 3.4%. Douglas-fir lost 52% of its original population of 375 trees for an average annual loss of 3.2%. Engelmann spruce lost 32% of 91 trees for an annual rate of 1.7%. Grand fir lost 31% of 764 trees, an annual rate of 1.7%. Western red cedar lost 9% of 879 trees at an annual rate of 0.44%. The other species, western larch, lodgepole pine, ponderosa pine, and western white pine, were too few to provide useful data.

In-growth added 101 trees to the plots, an average of eight trees per acre. Most of the in-growth was western red cedar (56%), grand fir (27%) or subalpine fir (11%). Only six in-growth trees were Douglas-fir, Engelmann spruce or western white pine.

The interaction of mortality and in-growth produced significant changes in plot species composition (Figure 21). Douglas-fir dropped from 17% to 11 % of the population over 22 years. Grand fir declined from 35% to 33% and western red cedar increased from 40% to 50% of the composition.

Figure 17 Percent survival of trees from the original tagged population by species. Harvest and ingrowth excluded.

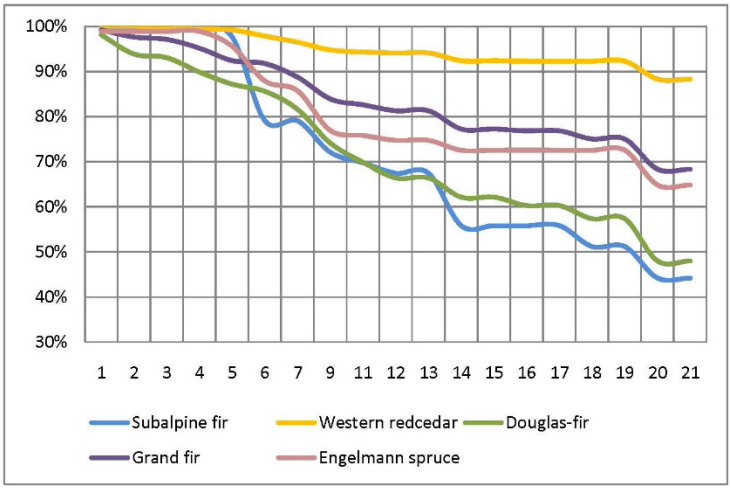


Figure 18. Periodic mortality as percent of live trees. Excludes harvested trees.

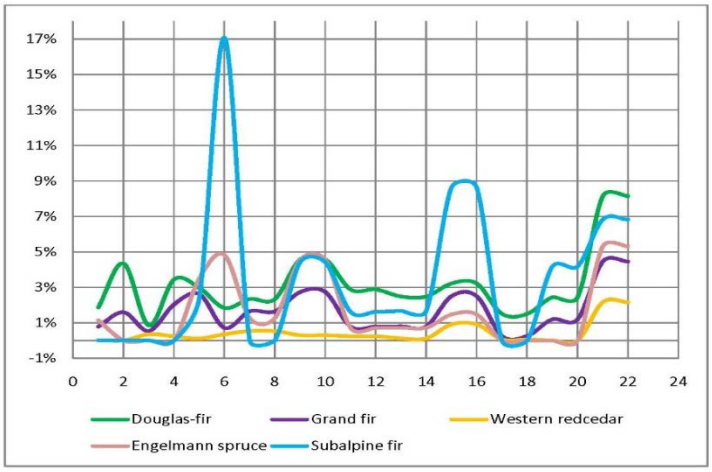
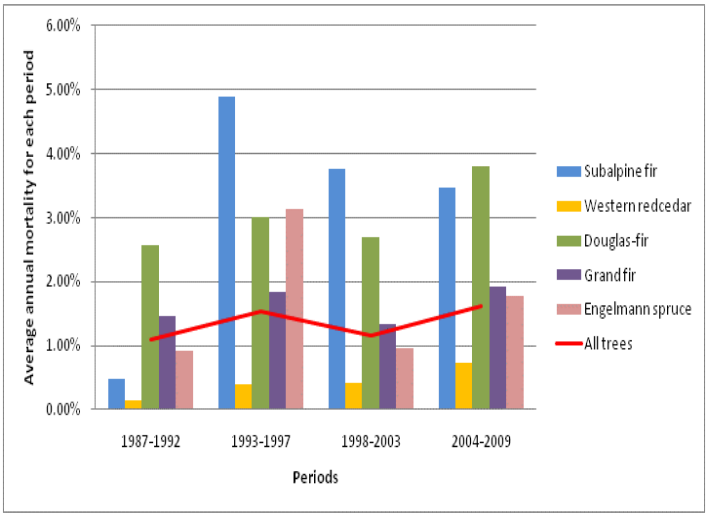


Figure 19. Average annual mortality rates as percent of trees by species and major interval.



In-growth

There were only 101 trees added to the plots as in-growth over the 22 year period. The western red cedar in-growth population had similar mortality rate at 11% to the non-in-growth population (Table 9 and Figure 17). The mortality rate of the grand fir in-growth population was much lower at 4% than the original population which had a 31% mortality rate. With only eleven subalpine fir, three Douglas-fir, two Engelmann spruce and one western white pine, these samples were insufficient to characterize in-growth mortality trends.

Root disease severity

The root disease severity class representing no root disease or low severity were far more common in 1987 than in 2009 (Figure 22). A dramatic increase in the highest severity classes, 8 and 9, accompanied this change. The average root disease severity score assigned at plot establishment was 4.1, including 38 plots with no root disease in 1987. There were 43 plots scored as severity 8 or 9 in 1987. In 2009 the average score had increased to 5.9 with 12 plots having no root disease and 87 plots scored severity 8 or 9.

The root disease severity score could be updated by the field crew on any mortality and damage check or re-measurement. While a third (34%) of the plot root disease severity scores were unchanged from 1987 to 2009, a majority of plots, 61%, increased severity by at least one class (Figure 23). Of the plots that did not change, almost half (44%) had already lost at least 75% of the overstory canopy, with severity scores of 7, 8 or 9, in 1987. Most were scored severity class 8. Six of the plots had a score of 0 in 1987 and remained in this class. Root disease was not detected on, or within 50 feet of these plots, throughout the 22 years.

Severity class 4 was the only other class that tended to remain unchanged. Eighteen of the 22 plots in this class in 1987 were still rated class 4 in 2009. Class 4 is not a particularly broad class; defined as having 20-30% canopy reduction due to root disease so the reason plots tended to stall in this class is not obvious.

There were 38 plots assigned root disease severity score 0 in 1987, indicating no evidence of root disease on or within 50 feet of the plot. Two of these plots were destroyed by harvest following windthrow (Cluster 15). Of the 36 remaining plots

Figure 20. Overall mortality by species in the original population of trees monitored for 22 years. In-growth and harvest excluded.

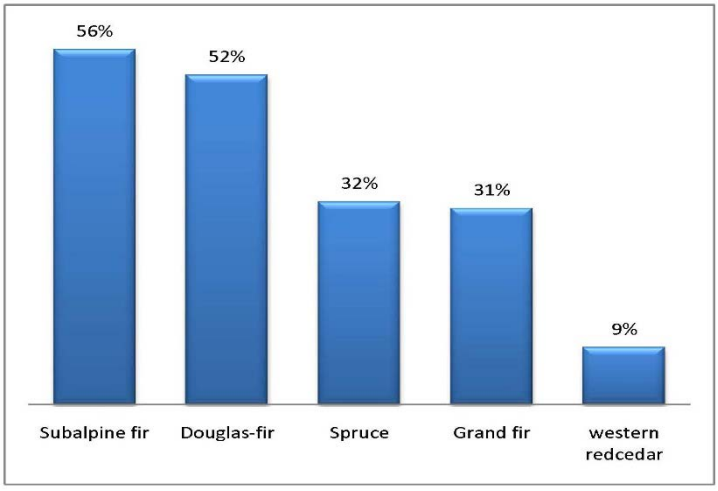


Figure 21. Shift in species composition of plots over 22 years as percent change in relative abundance of trees. Harvest excluded.

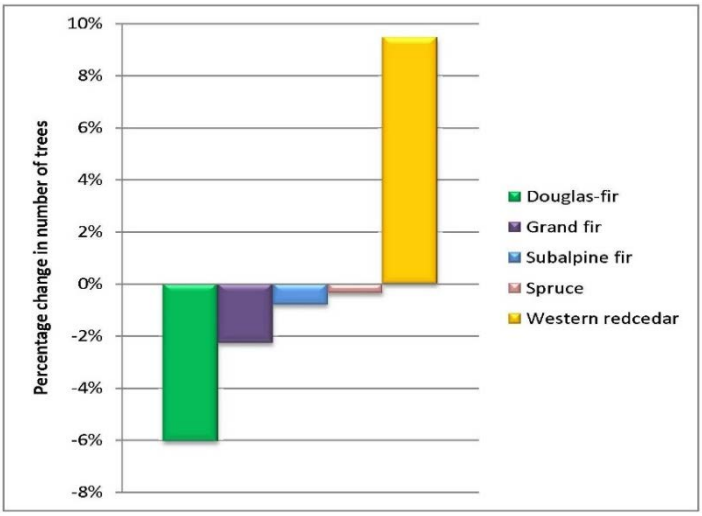
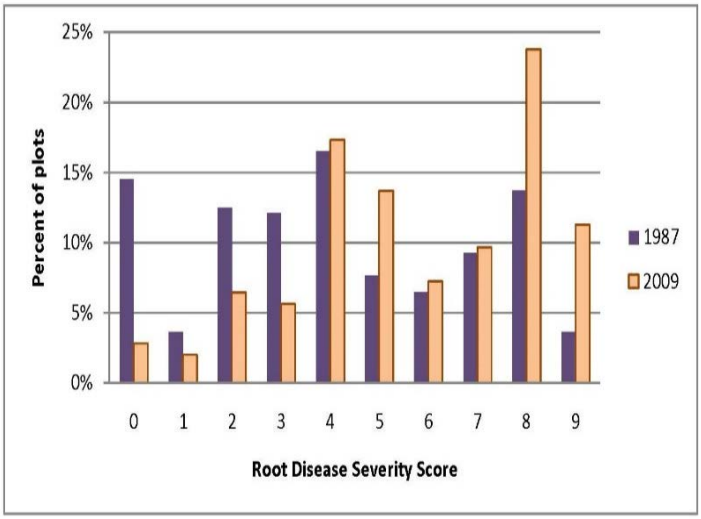


Figure 22. Distribution of root disease severity class by percent of plots in 1987 and 2009.



scored 0 in 1987, only seven remained in this class in 2009. The rest were distributed between scores of 1 and 6, with 12 in low classes, 1-3; and 17 in moderate classes 4-6. Among the plots with the largest increases in root disease severity were the ten that were severity 0 in 1987 yet had lost 30% to 75% of their canopy to root disease (severity classes 5 and 6) just 22 years later. These plots had a net loss that averaged 111 square feet of basal area per acre.

Overall, the average change in root disease severity was an increase of 1.7 over the 22 year period. Excluding the plots that were already severity 8 or 9 and had little or no opportunity to increase, the average change was an increase of 2.1. This represents a rate of roughly one severity class increase per decade.

Table 9. In-growth mortality over the 22-year monitoring period.

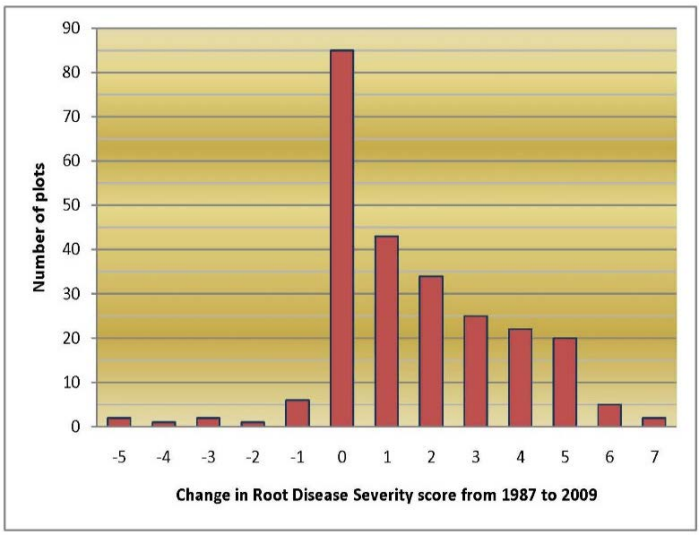
	Total trees	Mortality	% mortality	Years to death
Subalpine fir	11	3	27%	13
Western red cedar	57	6	11%	11
Douglas-fir	3	2	67%	14
Grand fir	27	1	4%	12
All Trees	***101[1/]***	***12***	***12%***	***12***

[1/] Includes two Engelmann spruce and one western white pine, all of which survived through 2009. [2/] Weighted average years to death.

Root disease severity and mortality

When the average plot root disease severity is compared to Douglas-fir or grand fir mortality (harvest excluded) on plots a nearly linear relationship is seen (Figures 24 and 25). Whether the metric is the percent of trees or the percent of basal area killed over the monitoring period, a similar linear relationship is observed. The slope of the regression of percent mortality on root disease severity is similar but somewhat steeper for Douglas-fir than for grand fir. The 15 plots that averaged severity score 6 over the 22 years had higher than expected rates of mortality of both Douglas-fir and grand fir. Root disease severity is dynamic through time and generally progresses in an increasing direction. Severity class 6 is broad, representing plots that have lost 50% to 75% of the overstory canopy. Our results suggest there may be a pulse of mortality that occurs in stands as they approach this stage of disease development.

Figure 23. Change in root disease severity from 1987 to 2009. Excludes the four abandoned plots.



Other predictors of mortality

The other site factors, i.e., slope, elevation, aspect, habitat type and potential vegetation type, were tested for their relationship to mortality rates. Neither slope nor aspect (figure 26) were useful predictors of mortality or root disease severity. The rate of mortality was somewhat higher on level sites, but not significantly so. Root disease severity was similar on all aspects.

Elevation and mortality

No relationship was seen between plot elevation and percent mortality by either trees or basal area. Figure 27 displays elevation plotted against percent mortality in the 22-year period, exclusive of harvest. The best fit was a polynomial curve but the R^2 for this curve suggests that elevation may account for only about 3% of the mortality variation.

Table 10. Habitat types encountered on plots.			
Habitat type	Abbreviation	# plots	# trees
Douglas-fir/ninebark	PSME-PHMA	4	14
Grand fir/ninebark	ABGR-PHMA	15	109
Grand fir/spirea	ABGR-SPBE	6	59
Grand fir/beadlilly	ABGR-CLUN	21	242
Grand fir/ginger	ABGR-ASCA	13	112
Grand fir/twinflower	ABGR-LIBO	3	41
Cedar/beadlilly	THPL-CLUN	50	655
Cedar/ginger	THPL-ASCA	75	888
Cedar/maidenhair fern	THPL-ADPE	26	233
Cedar/lady fern	THPL-ATFI	34	266
Subalpine fir/beadlilly	ABLA-CLUN	1	13

Habitat type

As previously stated, most plots had grand fir or western red cedar habitat types (Table 10). The plot frequencies for cedar/ginger, cedar/beadlilly, cedar/ladyfern, and cedar/maidenhair fern provide a particularly robust sample. The numbers for grand fir/beadlilly, grand fir/ginger and grand fir/ninebark are only fair, ranging from 13 to 21 plots each. Several habitat types occurred on only 1-4 plots, so interpretations of results from these types are tentative at best. These include subalpine fir/Clintonia (queencup beadlilly), grand fir/twinflower and Douglas-fir ninebark. Average root disease severity scores correlate well with mortality rates of Douglas-fir and grand fir by habitat type (Figure 28).

Significantly higher than average mortality rates for Douglas-fir were seen on grand fir/ginger and cedar/maidenhair fern habitat types. By 2009, 51% of the plots on grand fir habitat types and 35% of those on western red cedar types were scored root disease severity class 8 or 9. This indicated that there was no more than one overstory tree left alive on these plots, leaving them essentially non-stocked. Significantly lower rates were seen on the drier Douglas-fir and grand fir/ninebark types.

Potential Vegetation Type (PVT)

As with the habitat types, a few PVTs were well-sampled and others had inadequate samples (Table 11). Only a single plot represented the abla2 (cool-moist) PVT with 13 plot trees. Only three plots were classified as abgr2. These had a total of 41 trees. Psme2 was represented by just four plots with a total of 14 trees. The best sampled PVT was thpl2, a moderately cool and moist type that is very common on the Clearwater National Forest. There were 125 plots with 1,543 trees in this PVT.

Moist grand fir (abgr3), and western red cedar PVTs (thpl1 and thpl2) had distinctly higher mortality rates for Douglas-fir (Figure 29). Grand fir had similar mortality rates in each of the four best represented PVTs. The two PVTs with much lower mortality rates both had minimal samples. So the only conclusion we can draw confidently draw from these data is that Douglas-fir mortality rates were higher on western red cedar and moist grand fir PVTs than in the drier grand fir PVT, abgr1.

Table 11. Potential vegetation types encountered on plots.			
Code	Description	# plots	# trees
psme2	Moderately warm-dry	4	14
abgr1	Moderately warm-dry	21	168
abgr2	Moderately warm-moderately moist	3	41
abgr3	Moderately warm-moist	34	354
thpl1	Moderately-cool-wet	60	499
thpl2	Moderately-cool-moist	125	1543
abla2	Cool-moist	1	13

Causes of mortality

Among the most important advantages of frequent plot inspection is accurate identification of the causes of death. Of 614 trees that died between 1987 and 2009, only 10 trees (1.6% of dead trees and 2.4% of dead basal area) were undiagnosed (Figure 30). Root diseases were the leading cause of death. They were the direct cause of 78% of deaths, accounting for 67% of the dead basal area. They contributed to the death of an additional 11% of dead trees. Combined, root disease was diagnosed in 546 deaths (89% of dead trees and 83.5% of the dead basal area). Live-tree harvests accounted for 50 (8.2%) of the trees killed, half of these were western red cedar. Twenty of the 50 harvested trees had been diagnosed with root disease as well. Many windthrown trees also were salvaged but the cause of death was windthrow. Likewise, bark beetles were recorded attacking several windthrown trees but the cause of death had been windthrow. Grand fir was the most common victim of windthrow (Table 12) accounting for 33.5 of nearly 60 square feet of basal area windthrown on plots.

Table 12. Mortality between 1987 and 2009 by cause (square feet of basal area).

	Subalpine fir	Western red cedar	Douglas-fir	Grand fir	Lodgepole pine	Ponderosa pine	Engelmann spruce	Total
Bark beetles			3.4					3.4
Harvest	0.2	50.4		8.2			5.3	64.1
Root disease	10.7	65.7	169.5	281.3	0.4	5.3	38.9	571.7
Root disease/ bark beetles	0.8		56.3	10.2			5.7	73.0
Root disease/ salvage	3.0	0.2	9.9	10.0			11.5	34.6
Root disease /windthrow	1.1	1.3	14.5	18.8				35.7
Snow/ice				2.5				2.5
Topbreak		15.5						15.5
Unknown		18.9		0.6		0.7		20.2
Windthrow		5.9	5.1	24.3				35.3
All causes	**15.8**	**156.5**	**258.8**	**346.4**	**0.4**	**6.0**	**61.3**	**856.2**

The temporal patterns of mortality by cause

Root diseases

Pulses of mortality caused by root disease were evident throughout the monitoring period. Figure 31 illustrates the temporal pattern of root disease mortality for the 480 trees in which the death was attributed solely to root disease. The biannual measurement periodicity after year 6 may have influenced this observation. Note the large pulse of mortality in the final measurement year, 2009. Root disease was the single cause of death in all but a few cases. For the first time there were nearly as many western red cedar trees killed (32) in the 2008-2009 period as Douglas-fir (34). The contribution of western red cedar mortality contributed 25% of the mortality in that period.

Windthrow

Most of the windthrow-related mortality occurred between 1992 and 1997, with over half (53%) recorded in 1995 (Figure 32). Damages recorded in 1995 could have occurred any time between the plot damage checks in 1993

Figure 24. Douglas-fir mortality as percent of trees by plot root disease severity averaged over the 22-year monitoring period.

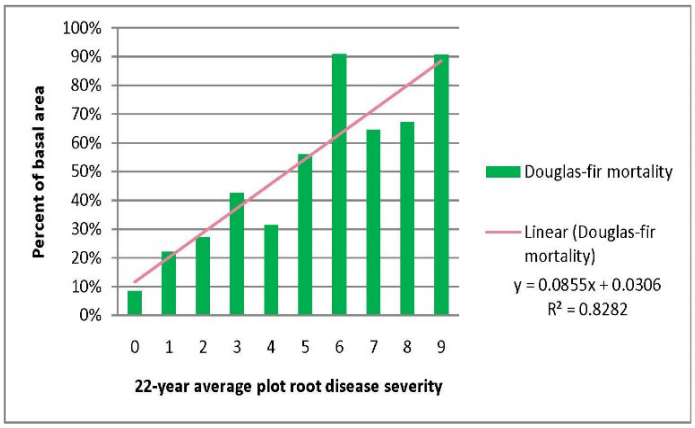


Figure 25. Grand fir mortality as percent of basal area by plot root disease severity averaged over the 22-year monitoring period.

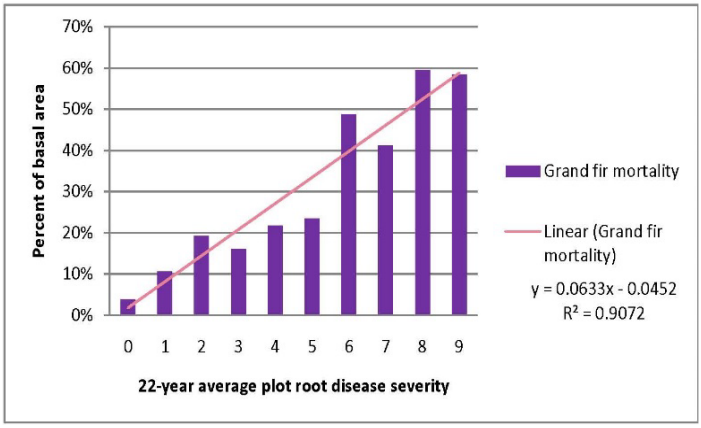


Figure 26. Aspect did not predict mortality or root disease severity.

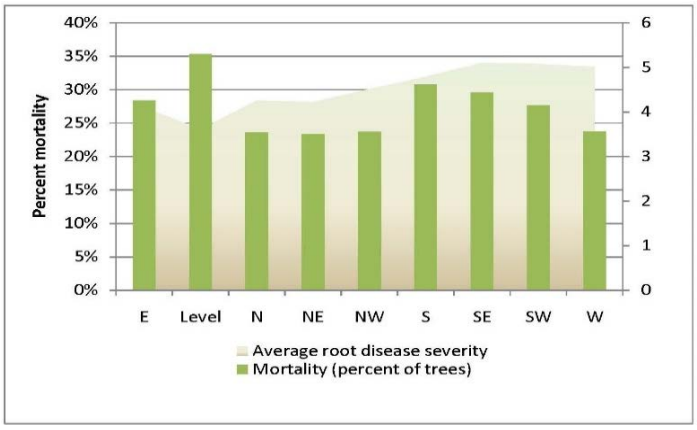


Figure 27. Elevation and percent mortality

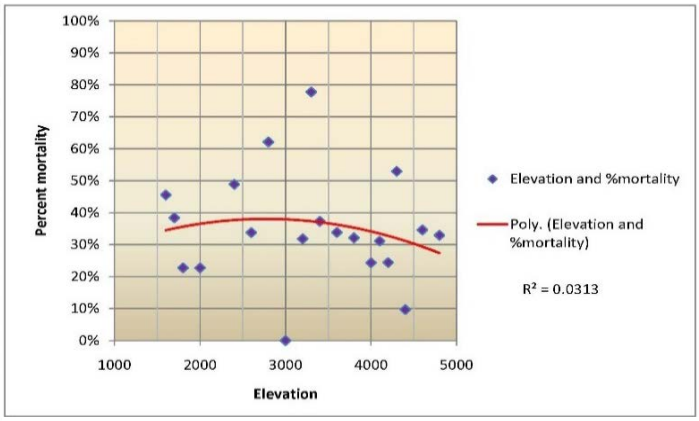


Figure 28. Cumulative Douglas-fir and grand fir mortality by habitat type. Shown with average root disease severity by habitat type.

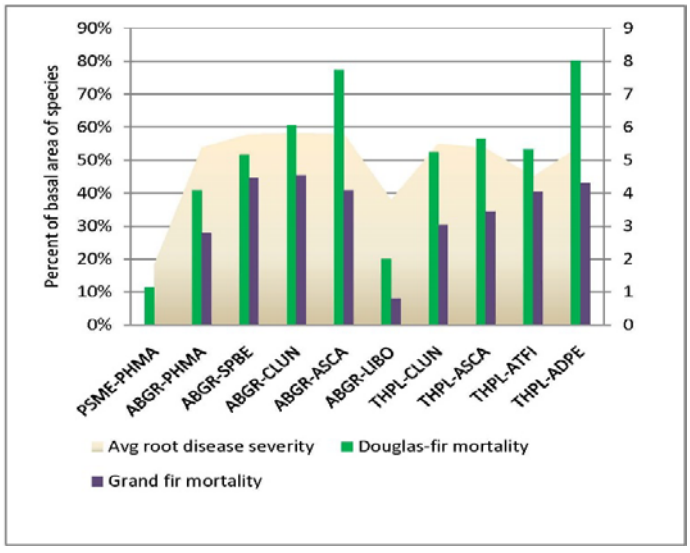


Figure 29. Douglas-fir and grand mortality as percent of basal area of the species by potential vegetation type as defined by Jones (2004).

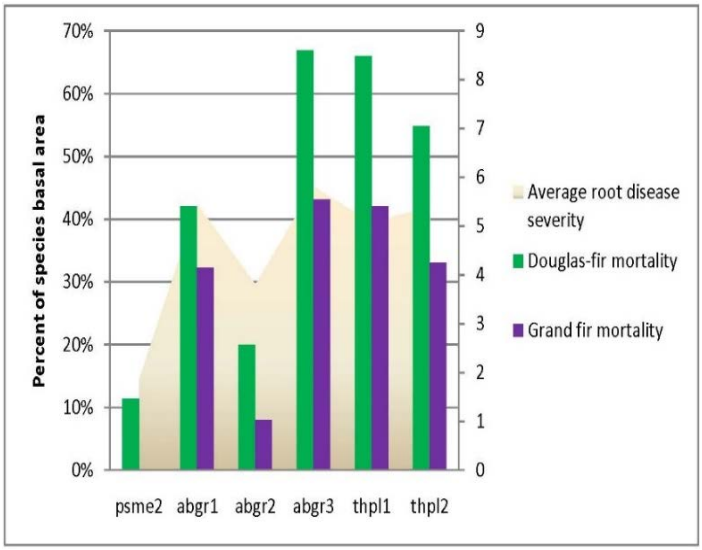


Figure 30. Causes of tree mortality between 1987 and 2009 shown as percent of mortality.

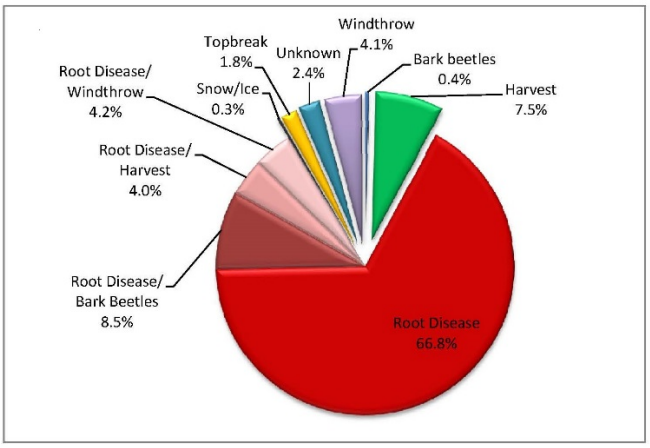


Figure 31. Root disease mortality by year. Includes only trees with root disease reported as the only cause of death.

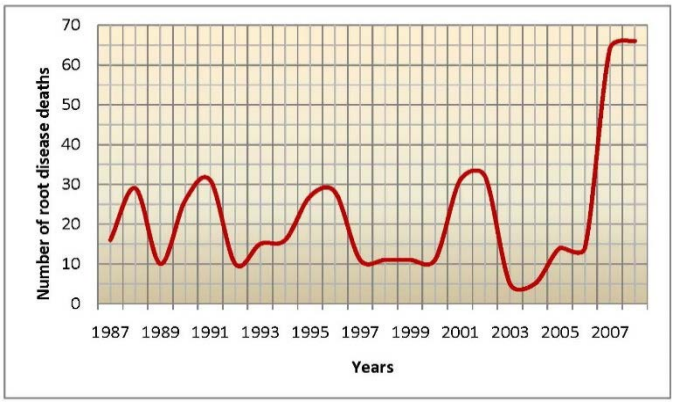
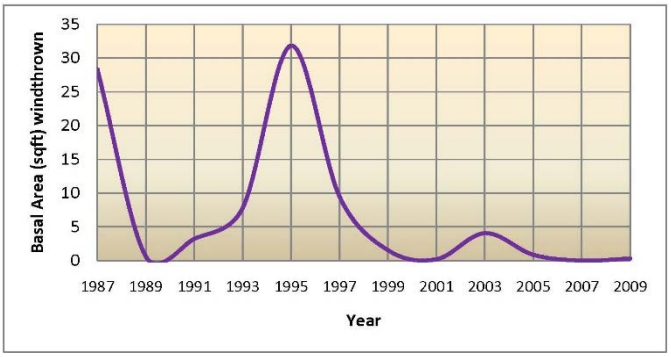


Figure 32. Windthrow mortality by year from 1987 to 2009. Includes all windthrow-related mortality. A total of 69 trees were windthrown on plots including 22 trees windthrown in 1987 just before plot establishment.



and 1995. The windthrow was not concentrated on a few plots, as we would have expected. In fact, it was scattered as one or two trees per plot on affected plots with the exception of one plot with six trees windthrown, five of which were recorded in 1995. However, a windthrow event in 1987 killed all but a few of the trees in cluster 15 shortly before plot establishment. Between the windthrow and subsequent salvage in 1992, the plot centers were lost and these plots were abandoned.

Bark beetles

Bark beetles contributed to deaths of five host species: Douglas-fir, grand fir, subalpine fir, Engelmann spruce and lodgepole pine. A total of 39 dead trees had bark beetle damages coded (Table 13). Of these, 26 (66%) had been attacked by Douglas-fir beetle (*Dendroctonus pseudotsugae* Hopkins). In two cases, the Douglas-fir beetles were considered the only cause of death. All but two Douglas-fir that had been attacked by bark beetles also had root disease. The peak period for Douglas-fir beetle-caused mortality on plots was 1996-2001. It is possible that this pulse of Douglas-fir beetle mortality developed from the windthrow recorded in 1995. As additional evidence, Douglas-fir beetle was reported as having infested two windthrown trees on plots in 1996-1997 and another in 2002-2003.

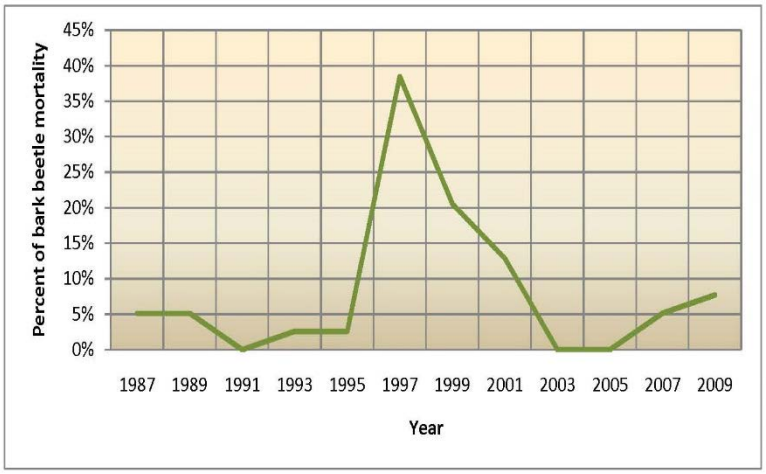
Table 13. Mortality associated with bark beetles. Number of trees killed in each period.

	1987	1989	1992	1995	1996-1997	1998-1999	2000-2001	2006-2007	2008-2009	Total
Subalpine fir							1		1	**2**
Douglas-fir		2		1	8	7	4	2	2	**26**
Grand fir	1		1		6	1				**9**
Engelmann spruce					1					***1***
Lodgepole pine	1									***1***
All species	***2***	***2***	***1***	***1***	***15***	***8***	***5***	***2***	***3***	***39***

Most of the fir engraver-caused mortality occurred in the 1996-1997 period. The nine grand fir and one subalpine fir killed by fir engraver were scattered across seven plots.

Although spruce beetle was recorded for several trees, only one of those trees died in the 1987-2009 period. The single lodgepole pine to die on the plots between 1987 and 2009 was killed by the combination of Armillaria root disease (caused by *Armillaria ostoyae* (Romagn.) Herink) and pine engraver beetles (*Ips pini* (Say)). Western balsam bark beetle was recorded just once as well, on a 9 inch dbh subalpine fir with root disease.

Figure 33. Percent of total bark beetle-caused mortality by the 2-year period in which it occurred.



A maximum of three trees died from bark beetle attack in a single period on a single plot, 501. A nearby plot, 503, had one tree killed by Douglas-fir beetle in the same period and two more in 1998-1999. Other than this cluster of mortality, the bark beetle associated mortality was scattered as one or two trees. Over the entire 22 years, the 39 trees killed by bark beetles were scattered across 20 plots and eight time periods, but 72% of the bark beetle mortality occurred between 1996 and 2001 (Figure 33).

Contributions to temporal patterns of mortality

The major causes of non-harvest mortality were root disease, windthrow, and bark beetles. Since root disease alone was the cause of 78% of deaths, it had the greatest influence on the temporal patterns of death. All three major causes of mortality conspired to produce a conspicuous peak between 1995 and 1997 (Figure 34). Root disease had a high period in 1995 and 1996, windthrow peaked in 1995, and bark beetles produced 38% of their mortality in 1996 and 1997. Another peak year for windthrow was 1987, which accounted for much of the mortality in the 1987-1989 period. Mortality in 2002-2003 was mostly root disease with an increasing share being western red cedar. By 2008-2009, one fourth of the mortality was western red cedar. This species largely accounted for the large increase in new mortality in this period.

Figure 34. Pattern of mortality shown as the number of trees by 2-year increments.

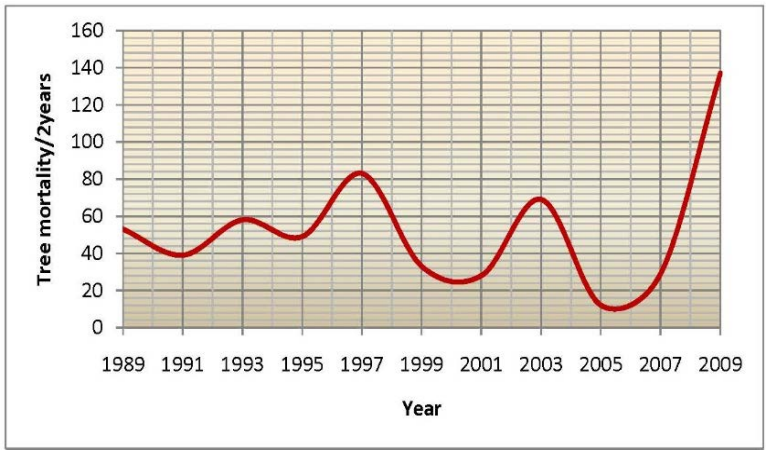


Figure 19 summarizes the mortality between the major re-measurement cycles. To compare the periods which have uneven lengths of 5 years in each of the first two and six in each of the last two, the average annual mortality rates were calculated. The “All trees” line shows the overall mortality in each period as a percent of live trees at the beginning of the period. Green harvested trees and those dead at the time of plot establishment were excluded but in-growth is included.

One of the most interesting trends is the steady increase of western red cedar mortality (Figure 35). About two thirds of the dead western red cedar had Armillaria root disease, often with annosus root disease as well. Since an increasing proportion of the plot composition is western red cedar, mortality of this species has had increasing impact on overall stocking.

Figure 35 illustrates the dramatic trend in western red cedar populations on the plots. The columns show the percent of the total cedar mortality that occurred in each 2-yr period. Dramatic peaks were seen in 2002-2003

and 2008-2009. The line graph represents the live cedar trees on plots at the end of each period including in-growth. From a high of 890 live trees in 1993, the plots dropped to a low of 827 in 2009. This was despite the addition of 57 trees through in-growth. The result is a total of 111 cedar trees that died on the plots. There were no trees harvested (including salvage) on the plots after 1997. Worth noting is the fact that the average dbh of western red cedar that died in 2003 - 2009 was 12.4 inches, a little more than two inches less than the average dbh of live trees in those time periods (14.6 and 15.6, respectively). Analysis of the crown class may provide further evidence of the circumstances of the dying western red cedar.

Root Disease pathogens and mortality

As previously stated, root diseases were the only damage reported in 67% of deaths and a contributing cause in another 11%. Therefore we have fairly detailed information on the species and relative impacts of the root pathogens. Of the 546 trees killed by root diseases, 79.3% were diagnosed with Armillaria root disease alone or in combination with other root pathogens (Figure 36). This is not surprising both because Armillaria root disease is known to be common in northern Idaho and because it is the easiest of the root diseases to diagnose. Basal resinosus and white mycelium fans in the cambium are common and easily observed symptoms and signs of the disease (Hagle 2009). Schweinitzii root and butt rot (*Phaeolus schweinitzii* (Fr.:Fr.) Pat.) was the second most common disease diagnosed, generally in combination with Armillaria root disease. Fir annosus root disease, caused by *Heterobasidion occidentale* Otrosina & Garbelotto, is a difficult disease to diagnose without considerable excavation to look for decay or culturing the fungus from root samples. Because it was necessary to restrict chopping and digging on plots, many trees with annosus root disease probably went undiagnosed other than to record that they had an "undetermined" root disease. However, even with this limitation, 125 trees were diagnosed with this disease over the 22-year monitoring period (Table 14).

Figure 35. Western red cedar mortality by period (percentage of the total WRC mortality by the period in which it occurred) and trend in the number of live western red cedar.

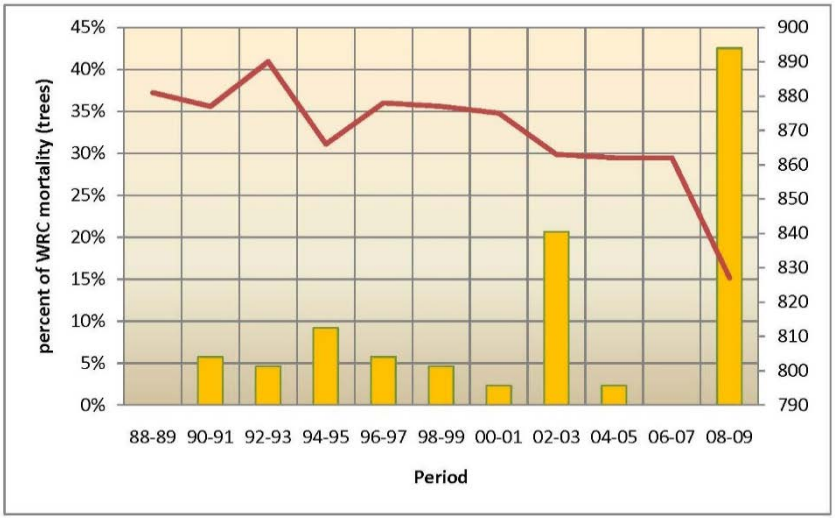
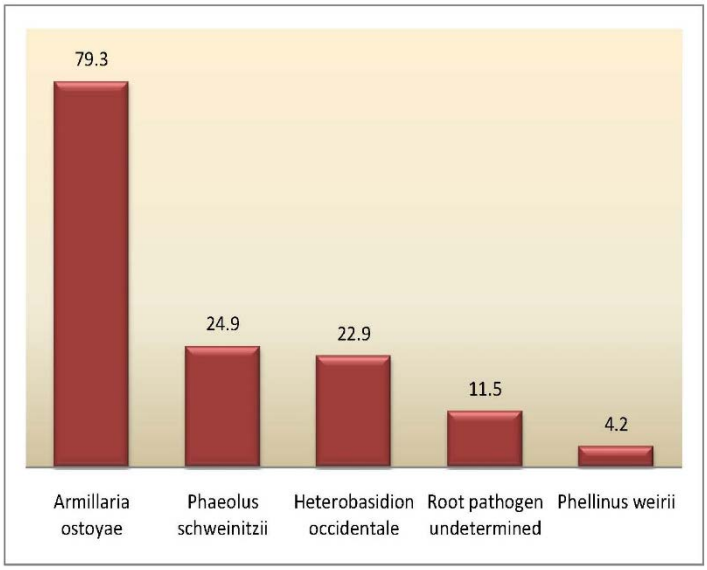


Figure 36. Pathogen frequencies as the percent of dead trees diagnosed with the disease caused by each fungus.



Phellinus weirii was identified on several western red cedar based on the distinctive fruiting body on the outer bark in the root collar area. The diagnosis of *Phellinus weirii* (Murrill) Gilb. on fourteen grand fir, four Douglas-fir and two Engelmann spruce may have been *Phellinus sulphurascens* Pilát, which is indistinguishable from *P. weirii* except by laboratory tests. At the time these plots were established, these two species of *Phellinus* were considered to be two patho-types of the same species, distinguishable based on the host. We have long known that they were ecologically distinct, however. It is likely that the laminated root rot recorded on grand fir, Douglas-fir and Engelmann spruce was *P. sulphurascens*.

Although Douglas-fir constituted only 17% of the live tree composition in 1987 (Table 3), it accounted for over 35% of the root disease-caused mortality (Table 14) and over 37% of all non-harvest mortality over the life of the project.

Table 14. Tree mortality by species and by pathogen and pathogen combinations.

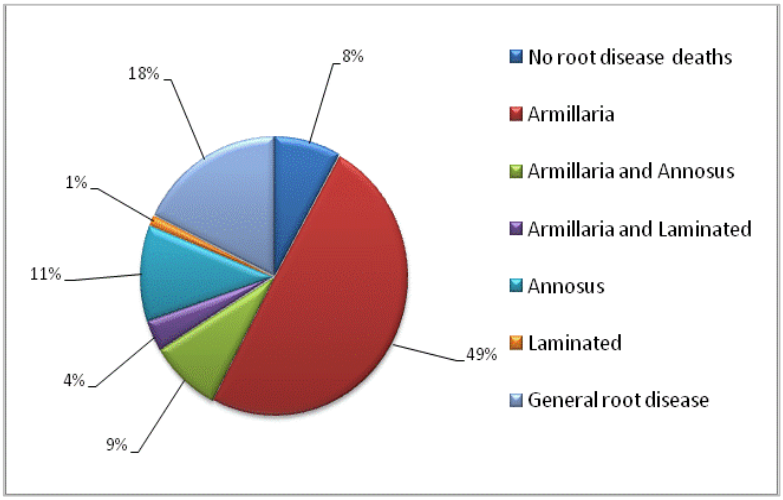
	Subalpine fir	Western red cedar	Douglas-fir	Grand fir	Lodgepole pine	Ponderosa pine	Engelmann spruce	All species	% of diagnoses
Armillara ostoyae	6	14	71	98	1	1	12	203	**37.2%**
Armillaria ostoyae/ Phaeolus schweinitzii	1	20	59	51				132	**24.2%**
Armillaria ostoyae/Heterobasidion occidentale	6	12	20	38			1	77	**14.1%**
Armillaria ostoyae/ Phellinus weirii		2	4	13			2	21	**3.8%**
Heterobasidion occidentale	11	11	12	6			4	44	**8.1%**
Heterobasidion occidentale/Phaeolus schweinitzii	1		2	1				4	**0.7%**
Phellinus weirii		1		1				2	**0.4%**
Root disease species undetermined	1	6	24	23			9	63	**11.5%**
All trees killed by root diseases	**26**	**66**	**192**	**231**	**1**	**2**	**28**	**546**	**100.0%**
Percent of diseased trees	**4.8%**	**12.1%**	**35.2%**	**42.3%**	**0.2%**	**0.4%**	**5.1%**	**100.0%**	

Grand fir was 35% of the live composition, and accounted for 42% of the root disease mortality. Western red cedar was 40% of the live trees and accounted for just 12% of the mortality, most of which occurred in the last few years.

Root disease in the final live tree population

By 2009, only 8% of the living trees were on plots that had no root disease deaths in the previous 22 years (Figure 37). This means that 92% of trees still to be monitored are on plots with at least one previous root disease mortality. Armillaria alone was diagnosed on plots containing half of the remaining live trees. Nearly one fifth of the live trees are on plots where the root disease was diagnosed but the identity of the pathogen has not been determined.

Figure 37. Distribution of remaining live-tree population by plot root pathogen. Pathogens that have caused at least one tree mortality on plot.



SUMMARY AND CONCLUSIONS

These plots in the Canyon Creek watershed have provided a rare opportunity to track changes over two decades in a variety of forest types and root disease conditions. Seven significant categories of

mortality-causing damages were recorded including root disease, bark beetles, windthrow and top breakage, snow and ice breakage, salvage harvesting and white pine blister rust.

The forests monitored in the Mex Mountain plots were mostly in mid-seral stages by 1987 based on their species composition, age and structure. Western white pine was conspicuously absent from the stands with a few remnant snags and stumps to testify to its earlier presence. Few other early seral species (western larch, ponderosa pine and lodgepole pine) remained in the stands as well. All standing dead trees and intact stumps were tagged at plot installation to document possible inoculum sources, track dead tree and stump deterioration, and document recent mortality prior to plot establishment. Nearly a third of the Douglas-fir were already dead in 1987. Western red cedar and grand fir made up most of the live tree component in 1987 with 40% and 35%, respectively.

After 22 years, there were 24% fewer trees alive, including in-growth, and slightly less live basal area on the plots than there had been in 1987. The species composition continued to shift as western red cedar increased to 50%, grand fir decreased slightly to 33% and Douglas-fir continued to drop from 17% in 1987 to 11% in 2009.

The percentage of plots with little or no forest canopy (crown classes 0-2) increased from 7% in 1987 to 21% in 2009. Root diseases were the main cause of this loss of forest canopy and of the shift in species composition. Salvage harvesting, windthrow and bark beetles were relatively minor influences.

Root disease severity rating proved a powerful tool for predicting the subsequent mortality over the 22-year monitoring period, particularly for Douglas-fir and grand fir. Root disease severity scoring has potential for development of hazard and risk assessment at the project level as well as for broad-scale applications.

Habitat type and potential vegetation type were fair predictors of mortality; particularly useful in combination with root disease severity class. Adding plots from other locations with a wider variety of habitat types and potential vegetation types could improve their use as mortality and root disease predictors. Other site factors including slope, aspect, elevation and topographic position were not able to predict mortality.

The high frequency of plot examination was crucial for credible identification of causes of death and it provided a unique opportunity to capture the temporal patterns of mortality. Annual and biannual rates of mortality varied greatly with pulses of mortality observed at irregular intervals. Some were partially explained by windthrow events and subsequent increases in bark beetle activity. For the most part, however, the reasons for pulses of mortality will require further research.

Additional analyses recommended

Greater depth of analysis could be done looking at the influences of site characteristics on mortality rates by species and by damaging agent. The deterioration rates of dead trees, in particular, how long they stand after death would probably be of interest for snag retention planning. It would be relatively easy to examine the data to determine if snag longevity varies by tree species, site factors or cause of death.

Fuels modeling and analysis of stand structure and composition changes that could influence fire behavior would be possible from these monitoring data. The correlation between root disease severity, fuels and predicted fire behavior could elucidate the future fire potential in these root disease altered landscapes.

Permanent plot data have been used periodically to validate and calibrate forest simulation models, Forest Vegetation Simulator (FVS), in particular. The root disease sub-model is driven by a set of keywords that have been developed based on model calibration using root disease permanent plot data. These should be reassessed and corrected as needed based on this new data analysis.

Several other data fields were recorded but not yet analyzed. For example, the non-forest cover component has been monitored by type (bare soil, rock, water, duff, etc.) or species (of vegetation), percent coverage on plots, and brush height. These data were not examined for this report. Likewise, crown class, 5-year increment growth, and tree volumes were not analyzed. Trends in non-tree cover, timber volume, canopy density as the crown competition factor, and structure trends are all analyses that could be completed using these data.

Supplemental data and analyses

Soils and parent materials likely influence the long term trends in mortality. These factors may be of particular importance in understanding the recent increases in western red cedar mortality. This species has relatively narrow ecological amplitude compared to species such as western white pine, Douglas-fir and grand fir. It is conceivable that the higher western red cedar mortality rates may be correlated with certain soils or parent materials. A soil survey or simply overlaying the plot locations on a soil or other geological attribute map may facilitate a relatively rapid and valuable analysis of these factors.

Weather events and climate trends also may have been a factor in the pulses or depression of mortality. This may be examined for each tree species assuming they can be expected to have different stress thresholds and responses.

Condition and disposition of the data

The monitoring data were collected on hard-copy field sheets which are stored at the District office. Electronic copies have been carefully edited to correct any errors. Each year of plot inspections or complete measurements are stored in Excel spreadsheets. They should be entered into the national stand database for long term storage but this will be a big task.

The future of the plots

The plots were established using base funds in the Northern Region, State and Private Forestry, Forest Health Protection program from 1987 to 1989. In 1990, the nationally-funded Pest Trend Impact Plot special project began funding the monitoring of these plots, first annually then then biannually. This program received special funding from national Forest Health Protection office. The program was discontinued in 2006 and local, Northern Region Forest Health Protection funding was again used to bring the plots through the 2007 inspection and 2009 complete re-measurement.

With volatile budgets, it is difficult to maintain funding for permanent plots. Yet, without permanent plots we would have very little knowledge of the impacts of root diseases in forests. The diseases are chronic and widespread, but not easily detected using remote sensing. Broad-scale assessment of impacts are difficult to achieve. By the final year of death from root disease, most trees will have lost nearly all of their foliage and be nearly impossible to detect from the air. Attempts to assess root disease mortality based on ground surveys have two severe limitations. The first is the difficulty of diagnosing the cause of death more than a year or two after tree death, and the second is the nearly-impossible task of correctly assessing the time since the tree died. As a result, we have erred greatly in both the cause of death and the rate of mortality.

Permanent plots currently are the only effective means to assess root disease impacts in forests. If these plots are discontinued, our knowledge of the trends in root disease impacts will cease to develop. Results from this report and others like it from the permanent plots last remeasured in 2005 to 2009 will become dated and their current validity doubtful.

Akin to the annual aerial surveys for insect damages that provide current data on insect activity, we will be challenged to provide up to date information on root disease impacts.

Permanent plots are not inexpensive but they are, in fact, relatively so compared to annual aerial surveys. The comparative impact of root diseases and forest insects such as bark beetles easily justifies a better balance between funding for aerial surveys and funding for root disease permanent plots. Additionally, the permanent plots monitor all causes of death as well as growth and other site and stand characteristics.

If monitored at a high enough frequency, they can provide accurate causal data for all of the significant tree damages. Ideally, the plots would be inspected yearly. But even with biannual inspection the cause of death can usually be clearly determined. Diagnosis becomes progressively less accurate over time after death and is likely to be possible in only about 40% of cases after 5 years. The temporal patterns of mortality will mostly be washed as the interval between inspections increases beyond two years. This would be especially true of weather-related pulses.

Five-year measurement intervals should still provide a good estimate of growth and mortality over the interval, but poor estimates of causes of damage.

Therefore, we recommend an inspection interval to record causes of mortality of no more than two years and a complete re-measurement interval of no more than six years.

What more can we expect to learn from these plots?

The last year of re-measurement, 2009, was also the year of the largest pulse of mortality. For the first time there were nearly as many western red cedar deaths as Douglas-fir. Will this upward trend in mortality rate of western red cedar continue? If so, are there site indicators for higher western red cedar mortality rates? Are weather patterns implicated?

Mantgem and others (2009) presented evidence of increasing mortality from long term plots in western conifers forests. Increasing rates of mortality were observed in species across the spectrum of life history traits (shade tolerant and shade-intolerant), suggesting that successional dynamics were an unlikely cause. They suggested that global climate change may have been a major contributor to the mortality trends. Although the plots have been monitored for a relatively short time, the increasing mortality rates of western red cedar on the Mex Mountain plots is consistent with the evidence presented by Mantgem and others (2009).

By 2009, 44% of plots had almost no canopy left. They were in the most severe root disease classes. The western red cedar habitat type plots can develop relatively root disease-tolerant western red cedar forest types. But the grand fir habitat type plots would seem to have nowhere to go. With 51% already in severity classes 8 and 9, what is the eventual fate of these plots? Will all grand fir habitat type plots eventually gather in the severity 8 and 9 classes? If so, we should have plans to look closely at the watershed implications, carbon sequestration, wildlife habitat qualities, and future timber supply. All may be seriously compromised by this widespread loss of forest canopy.

With only 11% of the forest composition still Douglas-fir, down from at least 20%, based on live and dead trees tagged in 1987, this species is rapidly going the way of western white pine, western larch, ponderosa pine and lodgepole pine before it. Will the last few Douglas-fir prove to be resistant to root disease? If so, they could be invaluable as seed sources.

How different will the attributes of a western red cedar, grand fir forest be than those of the seven-species forest that appears to have existed on these sites at some time before 1987?

These are some of the questions that are yet to be explored on these plots and many others are sure to be posed in coming years as the forest continues to transform in an unprecedented way.

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